NOAA Technical Memorandum NESDIS NGDC-59

DIGITAL ELEVATION MODELS OF THE NORTHERN GULF COAST: PROCEDURES, DATA SOURCES AND ANALYSIS

M.R. Love
C.J. Amante
B.W. Eakins
L.A. Taylor

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
August 2012

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite, Data, and Information Service

NOAA Technical Memorandum NESDIS NGDC-59

DIGITAL ELEVATION MODELS OF THE NORTHERN GULF COAST: PROCEDURES, DATA SOURCES AND ANALYSIS

Matthew R. Love[1]
Christopher J. Amante[1, 2]
Barry W. Eakins[2]
Lisa A. Taylor[3]

1. Earth Resources Technology, Inc., Annapolis Junction, Maryland
2. Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder
3. NOAA, National Geophysical Data Center, Boulder, Colorado

Funded by the American Recovery and Reinvestment Act (ARRA) of 2009.

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
August 2012

UNITED STATES DEPARTMENT OF COMMERCE

Rebecca Blank
Acting Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Mary M. Glackin
Under Secretary for Oceans and Atmosphere/Administrator

National Environmental Satellite, Data, and Information Service

Mary E. Kicza
Assistant Administrator

NOTICE

Mention of a commercial company or product does not constitute an endorsement by the NOAA National Environmental Satellite, Data, and Information Service. Use of information from this publication concerning proprietary products or the test of such products for publicity or advertising purposes is not authorized.

Corresponding project contact:
Lisa A. Taylor
NOAA National Geophysical Data Center
Marine Geology and Geophysics Division
325 Broadway, E/GC 3
Boulder, Colorado 80305
Phone: 303-497-6767
Fax: 303-497-6513
E-mail: Lisa.A.Taylor@noaa.gov
http://www.ngdc.noaa.gov/mgg/coastal/

Also available from the National Technical Information Service (NTIS)
(http://www.ntis.gov)

Contents

List of Figures

List of Tables

Digital Elevation Models of the Northern Gulf Coast: Procedures, Data Sources and Analysis

1. INTRODUCTION

In December 2010, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed two bathymetric–topographic digital elevation models (DEMs) of the Northern Gulf Coast (Figure 1). The DEMs were developed for NOAA's Coast Survey Development Laboratory (CSDL) through the American Recovery and Reinvestment Act (ARRA) of 2009[1] to evaluate the utility of the Vertical Datum Transformation tool (*VDatum*), developed jointly by NOAA's Office of Coast Survey (OCS), National Geodetic Survey (NGS), and Center for Operational Oceanographic Products and Services (CO-OPS) (http://vdatum.noaa.gov/).

The 1 arc-second DEM[2] referenced to North American Vertical Datum of 1988 (NAVD 88) was carefully developed and evaluated. A NAVD 88 to mean high water (MHW) 1/3 arc-second conversion grid derived from *VDatum* project areas was then created to model the relationship between NAVD 88 and MHW in the Gulf of Mexico region. NGDC combined the NAVD 88 DEM and the conversion grid to develop a 1/3 arc-second MHW DEM. The NAVD 88 DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Figures 2, 4 and 7) and the DEMs will be used for storm surge inundation and sea level rise modeling. This report provides a summary of the data sources and methodology used in developing the two Northern Gulf Coast DEMs.

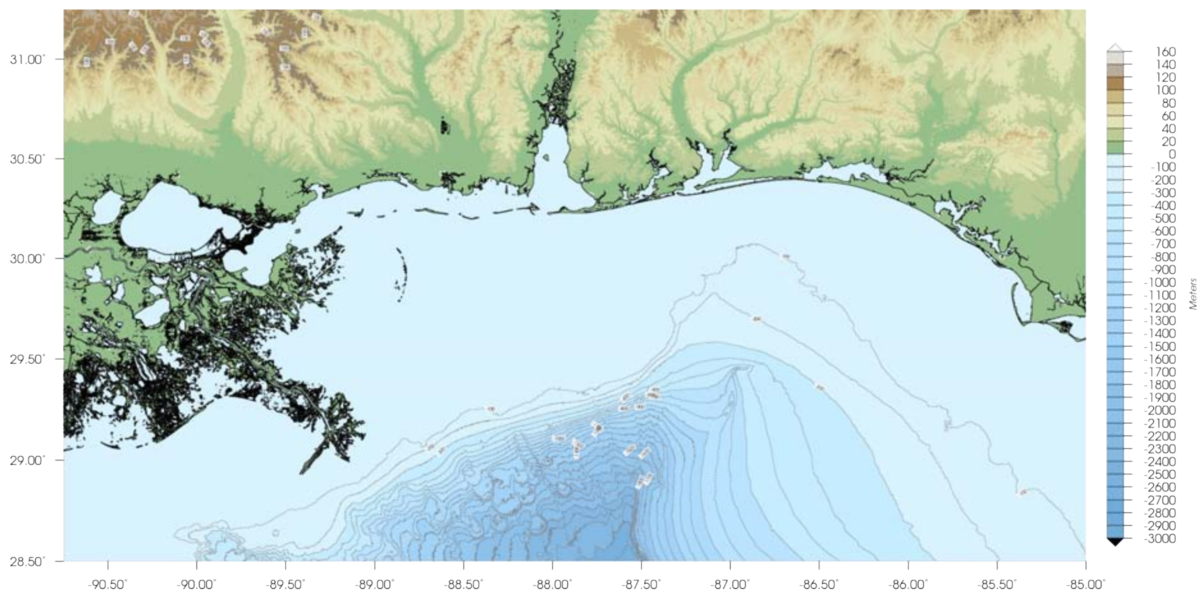


Figure 1. Shaded-relief image of the Northern Gulf Coast NAVD 88 DEM

[1]On Feb. 13, 2009, Congress passed the American Recovery and Reinvestment Act of 2009 at the urging of President Obama, who signed it into law four days later. A direct response to the economic crisis, the Recovery Act's three goals are to create new jobs as well as save existing ones, spur economic activity and invest in long-term economic growth and foster unprecedented levels of accountability and transparency in government spending (http://www.recovery.gov/Pages/home.aspx).

[2]The Northern Gulf Coast DEM is built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Mobile, AL, 1/3 arc-second of latitude is equivalent to 10.2641 meters; 1/3 arc-second of longitude equals 8.9371 meters

2. STUDY AREA

The Northern Gulf Coast DEMs cover the area from New Orleans, Louisiana in the west to Panama City, Florida in the east, including portions of Louisiana, Mississippi, Alabama, and Florida (Figure 2). The Northern Gulf Coast region is made of many inlets, bays, and lagoons and is intersected by numerous rivers, the largest of which is the Mississippi River, which drains into the Gulf of Mexico in Louisiana. Much of the land along the Northern Gulf Coast is, or was, marshland. Ringing the Gulf Coast is the Gulf Coastal Plain which stretches from Southern Texas to the western Florida Panhandle. The central part of the Gulf Coast, from eastern Texas through Louisiana, consists primarily of marshland. The eastern part of the Gulf Coast, predominantly Florida, is dotted with many bays and inlets. Due to the proximity of the Gulf to the subtropical waters of the Gulf of Mexico, the Northern Gulf Coast region is vulnerable to hurricanes as well as floods and severe thunderstorms.

Table 1. Specifications for the Northern Gulf Coast DEMs

Grid Area	Northern Gulf Coast
Coverage Area	-90.75 °, 31.25 °, -85.0 °, 28.5 °
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	North American Vertical Datum of 1988 (NAVD 88)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

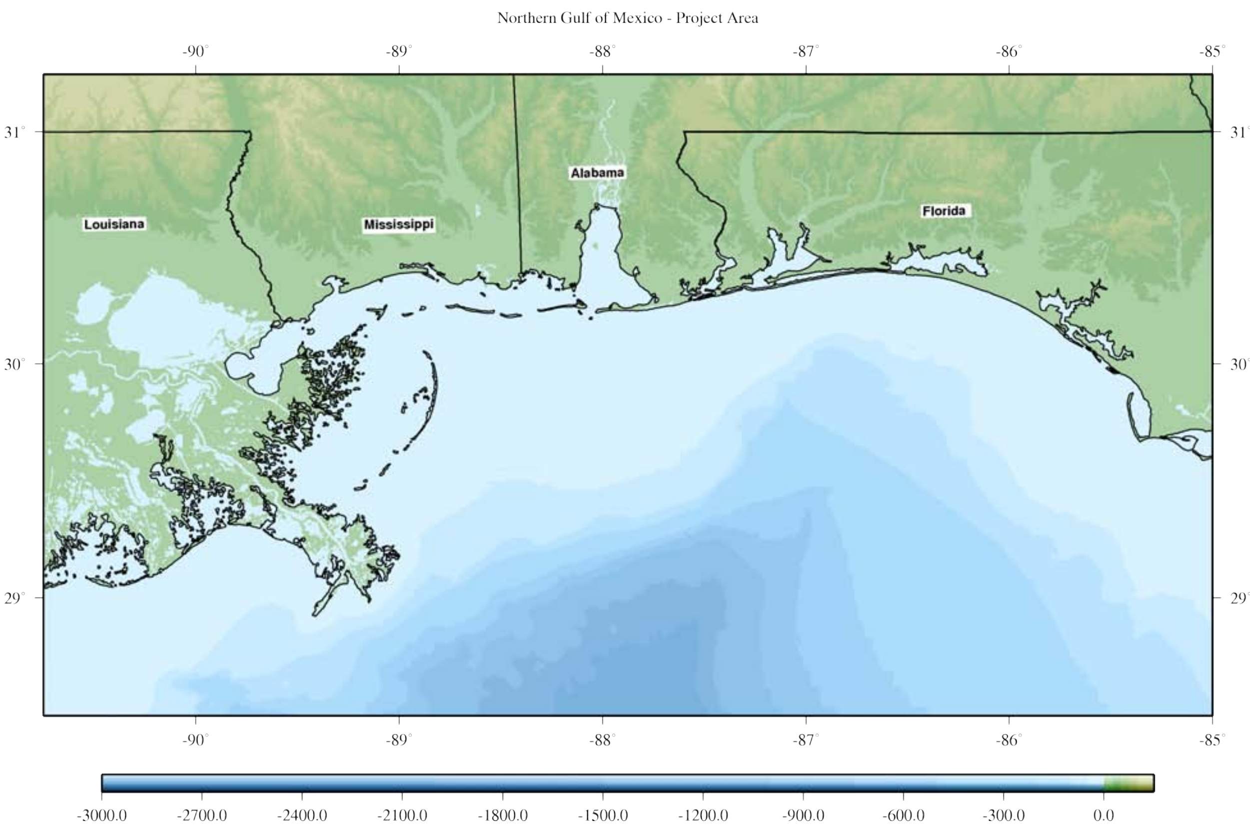


Figure 2. Extents of the Northern Gulf Coast project area and the states located within

3. SOURCE ELEVATION DATA

The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North America Datum 1983 (NAD 83)[3] and NAVD 88. NGDC developed a conversion grid derived from *VDatum* project areas to transform the Northern Gulf Coast DEM in its entirety from NAVD-88-to-MHW, for modeling of maximum flooding (Section 3.3.4 & 3.3.5). Data were gathered in an area slightly larger (∼5%) than the DEM extents. This 'data buffer' ensures that gridding occurs across rather than along the DEM boundaries to prevent edge effects. Data processing and evaluation, and the DEM assembly and assessment are described in the following subsections.

3.1 Data Sources And Processing

Coastline, bathymetric, and topographic digital datasets (Tables 2, 3, and 4) were obtained from several U.S. federal agencies: NOAA's NGDC, OCS and Coastal Services Center (CSC); the United States Geological Survey (USGS); and the United States Army Corps of Engineers (USACE). The datasets were displayed with Earth Systems Research Institute (ESRI) ArcGIS, ESRI Imagery World 2D Online World Imagery 2D, and Applied Imagery Quick Terrain Modeler software (QT Modeler) to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using NOAAâĂŹs Vertical Datum Transformation (*VDatum*)[4] software, and ESRI ArcGIS, based upon data from NOAA tide stations (see Section 3.2.1).

3.1.1 Coastline

Coastline datasets of the Northern Gulf Coast region were obtained from a variety of sources, including OCS and NGDC. The coastline dataset used in developing a combined detailed coastline was the NGDC world vector shoreline (Table 2, Figure 3). This dataset provided a detailed MHW coastline for the entire Northern Gulf Coast coverage area. NGDC did not use a coastline dataset over areas where pre-built DEMs were available (Section 3.1.4). See sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

Table 2. Coastline datasets used in compiling the Northern Gulf Coast DEMs

Source	***Year***	***Data Type***	***Spatial Resolution***	***Original Horizontal Datum/Coordinate System***	***Original Vertical Coordinate System***	***URL***
NOAA NGDC NOS	1994	Composite vectorized coastline	2.0 mm at 1:250,000	WGS 84 geographic	MHW	http://rimmer.ngdc.noaa.gov/

[3]The horizontal difference between NAD 83 and World Geodetic System of 1984 (WGS 84) geographic horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEM. Many GIS applications treat the two datums as identical, so do not actually transform data between them, and the error introduced by not converting between the datums is insignificant for our purposes. NAD 83 is restricted to North America, while WGS 84 is a global datum. As tsunamis may originate most anywhere around the world, tsunami modelers require a global datum, such as WGS 84 geographic, for their DEMs so that they can model the waveâĂŹs passage across ocean basins. This DEM is identified as having a WGS 84 geographic horizontal datum even though the underlying elevation data were typically transformed to NAD 83 geographic. At the scale of the DEM, WGS 84 and NAD 83 geographic are identical and may be used interchangeably.

[4]*VDatum* is a free software tool being developed jointly by NOAA's NGS, OCS, and CO-OPS. *VDatum* is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums.

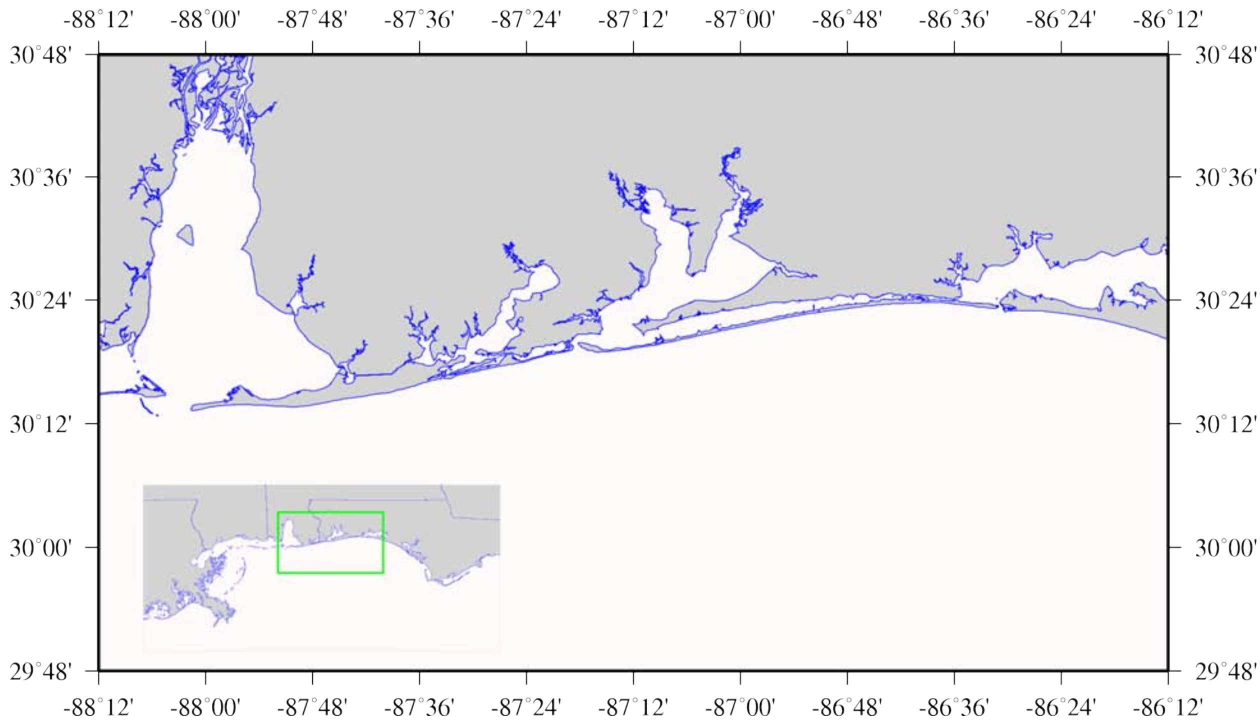


Figure 3. Portion of coastline dataset used in the development of the Northern Gulf Coast DEMs.

3.1.2 Bathymetry

Bathymetric datasets available in the Northern Gulf Coast region included 322 National Oceanic Survey (NOS) hydrographic surveys, and 33 ENCs (Table 3; Figure 4). NGDC reviewed but did not use 10 multibeam surveys. See sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

Table 3. Bathymetric datasets used in compiling the Northern Gulf Coast DEMs

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Coordinate System*	*URL*
NOS-CSDL	1888 to 2001	Hydrographic survey soundings	Ranges from 1:5,000 to 1:80,000	NAD 83 geographic	MLLW or MLW	http://www.nauticalcharts.noaa.gov/csdl/welcome.htm
ENC/OCS		Hydrographic point data	Ranges from 1:20,000 to 1:458,596 (varies by chart)	WGS 84 geographic	MLLW	http://www.nauticalcharts.noaa.gov

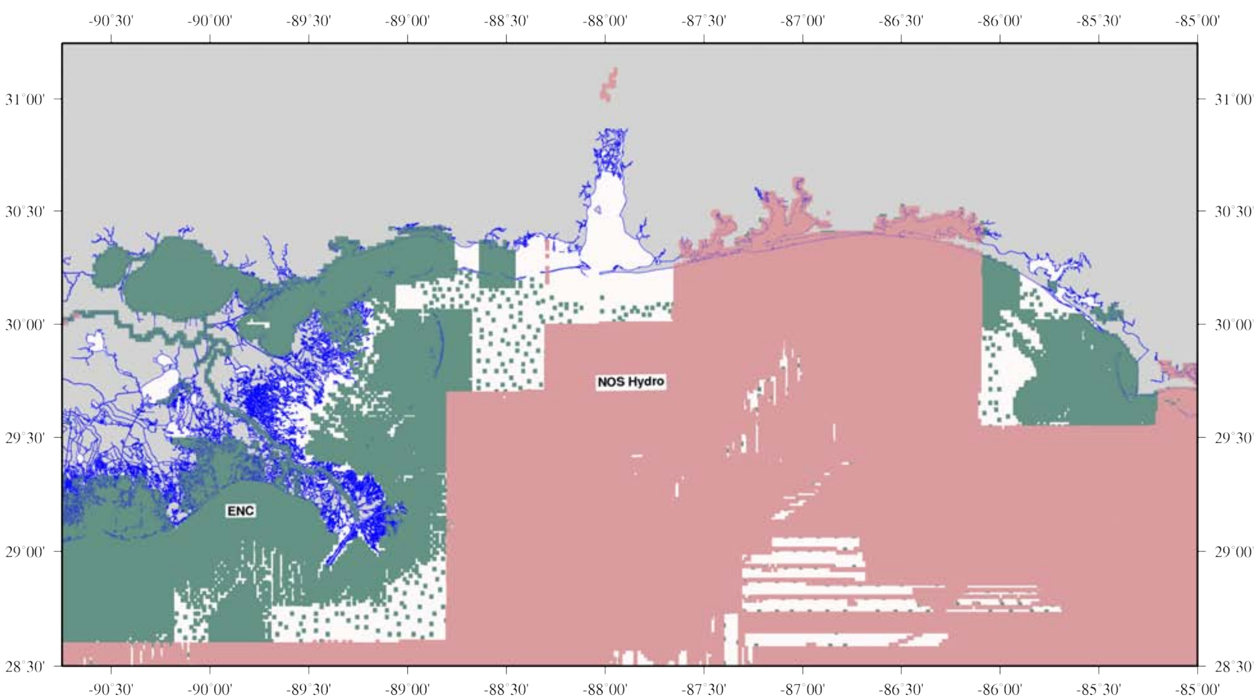


Figure 4. Bathymetric data sources available in the Northern Gulf Coast region.

1) NOS Hydrographic Surveys

A total of 322 NOS hydrographic surveys conducted between 1873 and 2003 were available for use in the development of the Northern Gulf Coast DEMs (Figure 5). CSDL provided NGDC with a non-superceded database of NOS hydrographic surveys. The database excluded NOS survey data if there were more recent NOS survey data at the same location. NGDC also manually edited older NOS hydrographic survey data that were inconsistent with USACE soundings in more recently dredged channels. The data were vertically referenced to mean lower low water (MLLW) or mean low water (MLW) and horizontally referenced to NAD 83 geographic. Survey data were used in an area 0.05 degree (∼5%) larger than the Northern Gulf Coast DEM extent to support data interpolation across grid edges. Data point spacing for the NOS surveys varies by collection date. In general, earlier surveys had greater point spacing than more recent surveys. NOS survey data were clipped to bathymetric–topographic datasets using Python[5] and transformed from MLLW or MLW to NAVD 88 using *VDatum*. The data were displayed in ESRI ArcMap and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to the various topographic and bathymetric data, the final coastline, and OCS Raster Navigational Charts (RNCs). See Sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

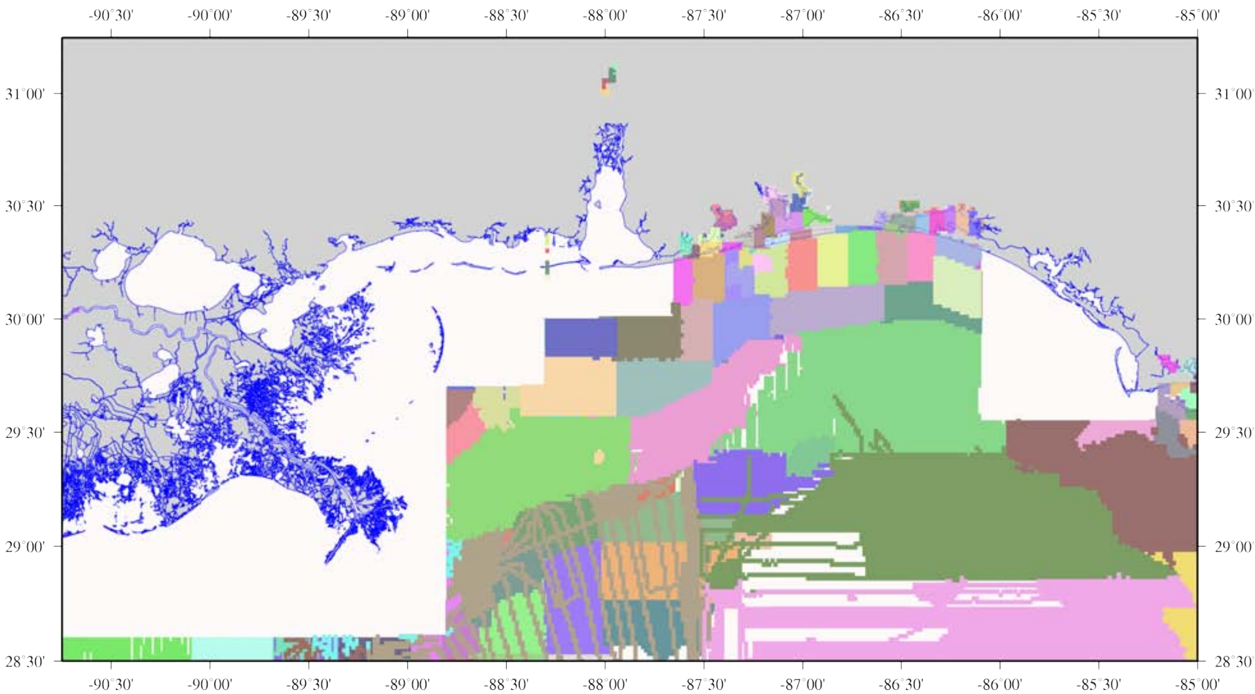


Figure 5. NOS digital hydrographic survey coverage in the Northern Gulf Coast region. Some soundings from earlier surveys were not used as they have been superseded by more recent surveys.

[5]Python is an interpreted, general-purpose high-level programming language whose design philosophy emphasizes code readability. Python is free and open source software. http://www.python.org/

2) OCS Electronic Navigational Charts

Thirty-three ENC bathymetric datasets were available from OCS in the Northern Gulf Coast coverage area (Figure 6). The ENCs were downloaded from the OCS web site (http://www.nauticalcharts.noaa.gov), and were horizontally referenced to NAD 83 geographic and vertically referenced to MLLW. The data were reviewed and compared to the coastline and to the corresponding RNCs. See Sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

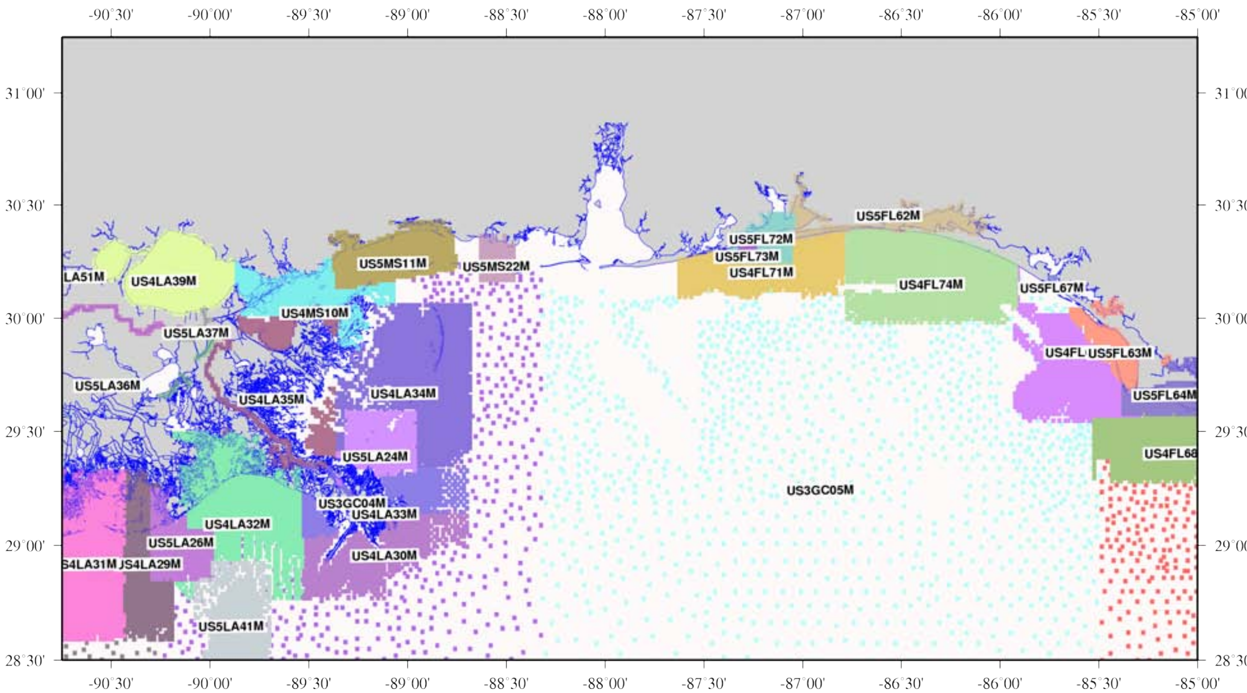


Figure 6. OCS ENC bathymetric datasets available in the Northern Gulf Coast region.

3.1.3 Topography

The topographic datasets used to build the Northern Gulf Coast DEMs include: USGS National Elevation Dataset (NED) 1 arc-second DEMs (Table 4; Figure 7). See Sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

Table 4. Topographic Datasets Used in Compiling the Northern Gulf Coast DEM

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Coordinate System*	*URL*
USGS	1999	Bare-earth lidar	1 - 5 meters	WGS 84 geographic	NAVD 88 (meters)	http://ned.usgs.gov/
FDEM	2009	Bare-earth contours	2 feet	NAD 83 HARN	NAVD 88 (feet)	http://www.floridadisaster.org/gis

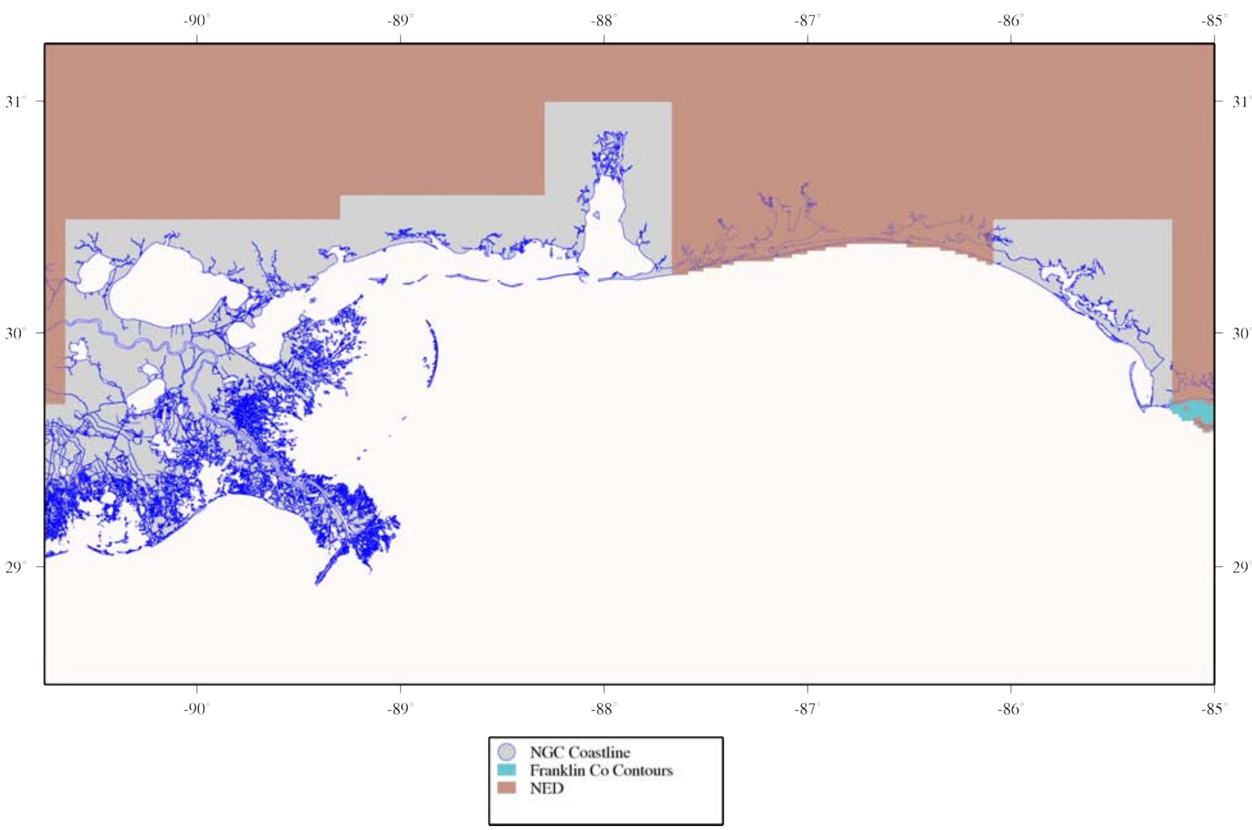


Figure 7. Topographic data sources in the Northern Gulf Coast region.

1) USGS NED

The USGS NED provided complete 1 arc-second bare-earth DEM (NED 1 DEM) coverage of the Northern Gulf Coast region[6] (Figure 8). The NED 1 DEM was utilized in gridding the Northern Gulf Coast DEMs. The extracted bare-earth elevations from the NED 1 DEM have a reported vertical accuracy of +/- 7 to 15 meters depending on source data resolution. The NED 1 DEM was derived from USGS quadrangle maps and aerial photographs based on topographic surveys, and has been revised using data from 1999 to 2009. The NED DEMs were converted to *xyz* for gridding using Python and GDAL. See Sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

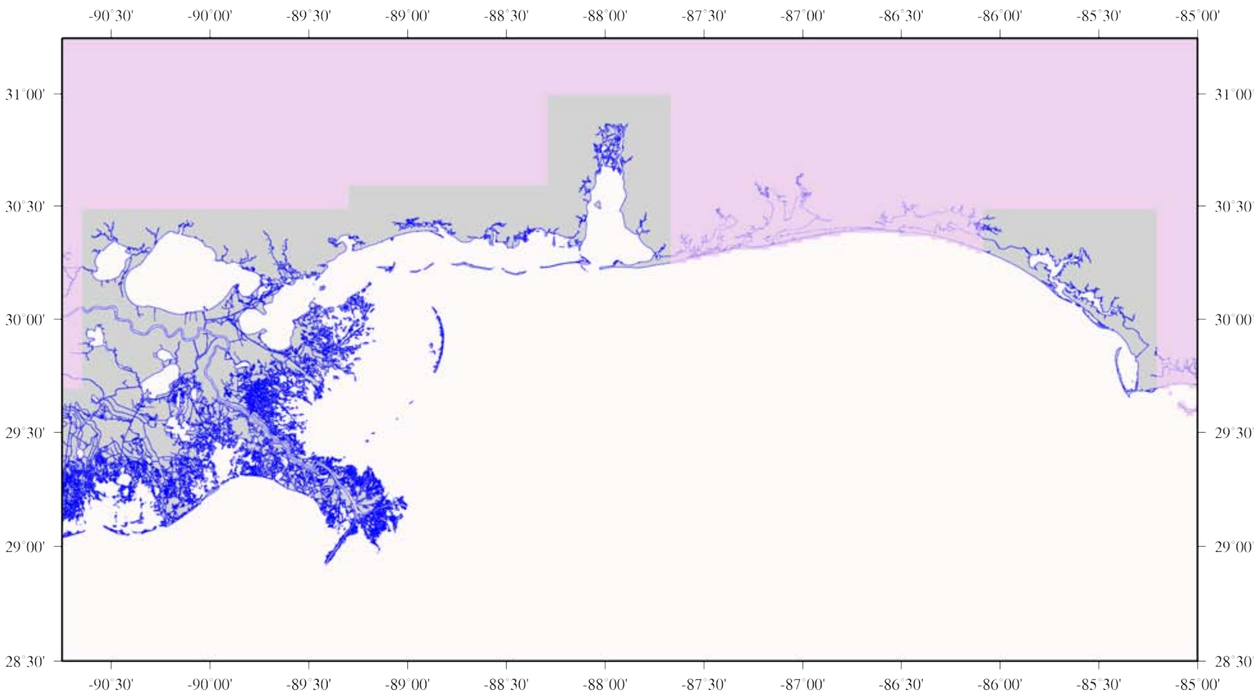


Figure 8. USGS NED 1-arc second DEMs used in the development of the Northern Gulf Coast DEMs

[6]The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Georgia. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD 83, except for AK, which is NAD 27. The vertical datum is NAVD 88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED web site]

2) FDEM contoured lidar

The topographic lidar datasets used in compiling the Northern Gulf Coast DEM were collected in 2006 and 2009 for a variety of organizations, including FDEM, the Florida Water Management Districts, the Florida Fish and Wildlife Conservation Commission, the Florida Department of Environmental Protection, the USACE Jacksonville District, and other state and federal agencies. The ultimate goal of this project was to use the lidar data as new elevation inputs for updated Sea, Lake, and Overland Surges from Hurricanes (SLOSH) data grids, resulting in updates of the Regional Hurricane Evacuation Studies (RHES; http://www.saw.usace.army.mil/floodplain/Hurricane%20Evacuation.htm) for the state.

FDEM coastal lidar for Franklin County, FL (Figure 9) were downloaded by NGDC from the FDEM GIS portal (http://www.floridadisaster.org/gis) as 2ft vector contours. The 2009 coastal lidar data were horizontally referenced to NAD 83 HARN and vertically referenced to NAVD 88. The vector contours were converted to *xyz* points to be used in the final gridding process using Python and GDAL. See Sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

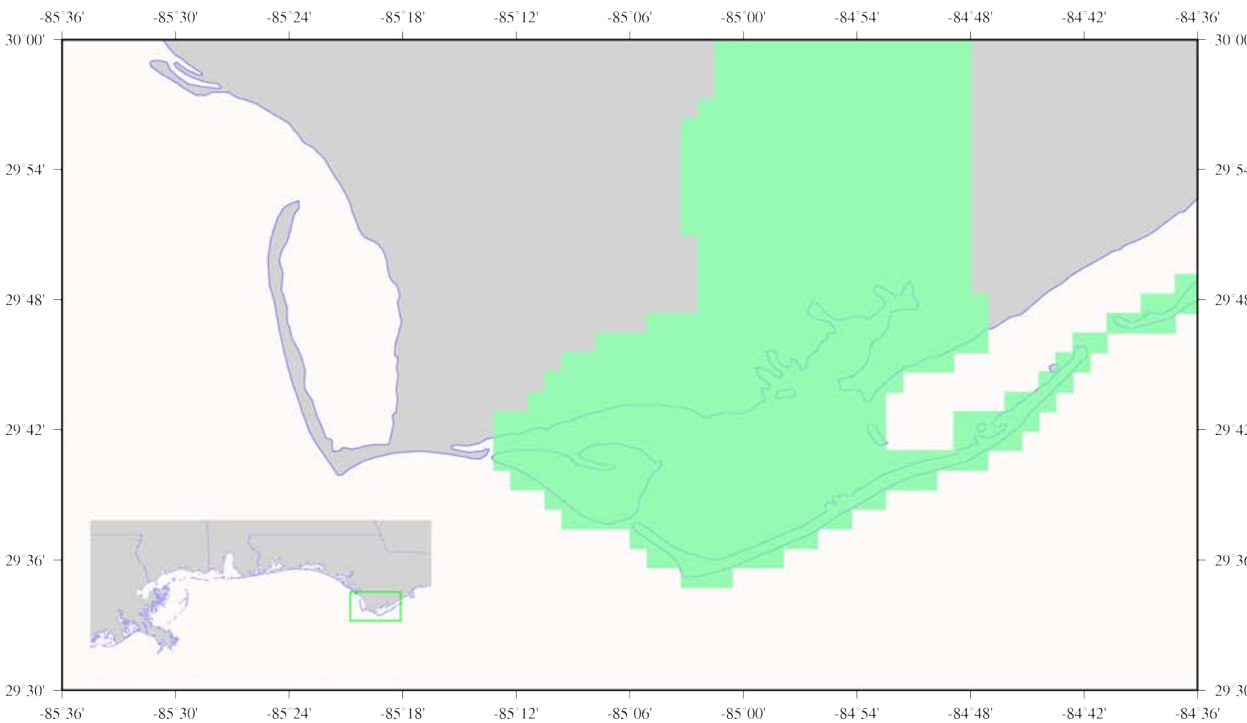


Figure 9. FDEM data sources used in the development of the Northern Gulf Coast DEMs

3.1.4 *Bathymetry–Topography*

The combined bathymetric–topographic datasets used to build the Northern Gulf Coast DEMs include: NGDC's Southern Louisiana DEM, NGDC's New Orleans, LA DEM, NGDC's Mobile, AL DEM, NGDC's Biloxi, MS DEM and NGDC's Panama City, FL DEM (Table 5; Figure 10). See Sections 3.2.1 and 3.2.2 for horizontal and vertical datum transformation specifics, respectively.

Table 5. Bathymetric/Topographic Datasets Used in Compiling the Northern Gulf Coast DEMs

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Coordinate System*	*URL*
NGDC Southern Louisiana DEM	2010	Digital Elevation Model	1/3 arc-second	WGS 84 geographic	NAVD 88 (meters)	http://wwwdev.ngdc.noaa.gov/mgg/inundation/hurricane/hfip.html
NGDC New Orleans, LA DEM	2009	Digital Elevation Model	1/3 arc-second	WGS 84 geographic	NAVD 88 (meters)	http://www.ngdc.noaa.gov/mgg/inundation/vdatum/vdatum.html
NGDC Biloxi, MS DEM	2007	Digital Elevation Model	1/3 arc-second	WGS 84 geographic	MHW (meters)	http://www.ngdc.noaa.gov/mgg/inundation/tsunami/
NGDC Mobile, AL DEM	2009	Digital Elevation Model	1/3 arc-second	WGS 84 geographic	NAVD 88 (meters)	http://www.ngdc.noaa.gov/mgg/inundation/vdatum/vdatum.html
NGDC Panama City, FL DEM	2009	Digital Elevation Model	1/3 arc-second	WGS 84 geographic	NAVD 88 (meters)	http://www.ngdc.noaa.gov/mgg/inundation/vdatum/vdatum.html

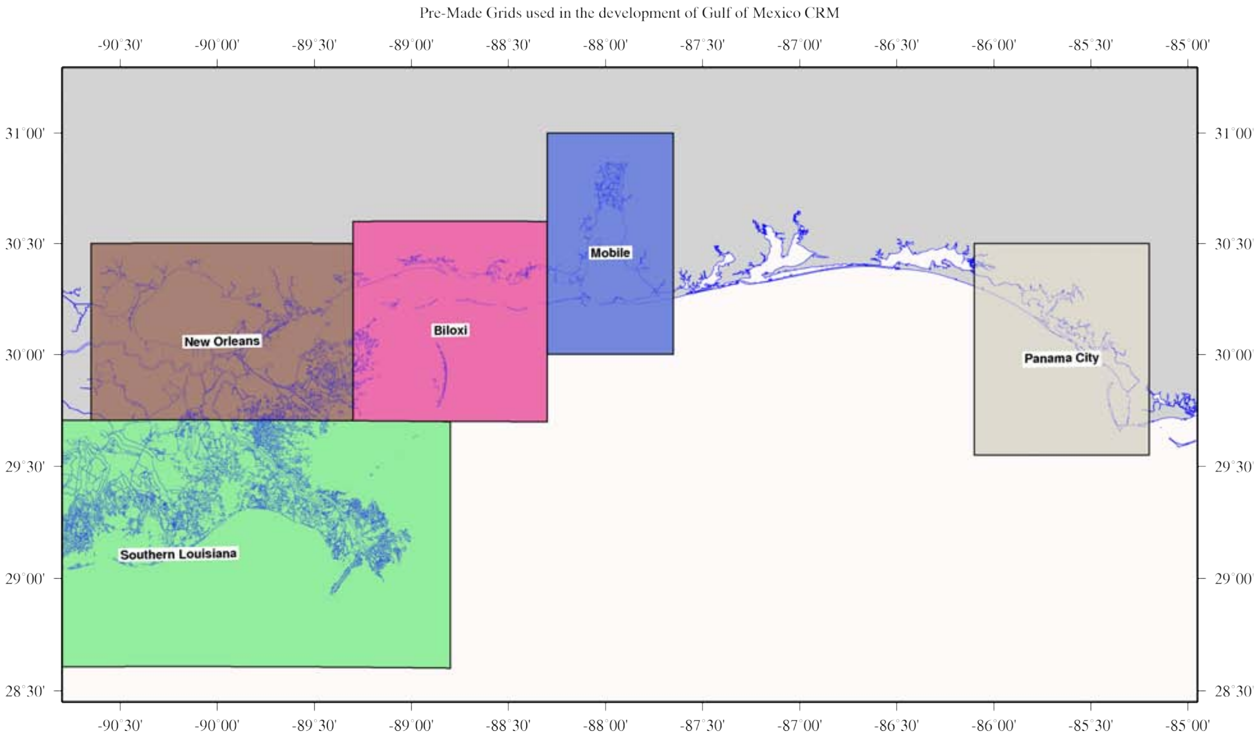


Figure 10. Bathymetric/Topographic data sources used in compiling the Northern Gulf Coast DEMs

1) NGDC Southern Louisiana DEM

A 1/3 arc-second NAVD 88 DEM of Southern Louisiana [Love, et al., 2010] was downloaded from the NGDC for use in the development of the Northern Gulf Coast DEM (Table 5 Figure 10). The DEM was developed for the Hurricane Forecast Improvement Project (HFIP), with the purpose of developing a new methodology for building companion structured and unstructured DEMs. The Southern Louisiana DEM was contructed to meet the CSDL specifications, based on storm surge and sea level rise modeling requirements. The DEM was subsampled to 1 arc-second and converted to *xyz* format for gridding using GMT, Python and GDAL.

2) NGDC New Orleans, LA DEM

A 1/3 arc-second NAVD 88 DEM of New Orleans, Louisiana [Love, et al., 2009] was downloaded from the NGDC for use in the development of the Northern Gulf Coast DEM (Table 5 Figure 10). The DEM was developed for NOAA's CSDL through the ARRA of 2009 to evaluate the utility of *VDatum*, developed jointly by NOAA's OCS, NGS, and CO-OPS (http://vdatum.noaa.gov/). The DEM was subsampled to 1 arc-second and converted to *xyz* format for gridding using GMT, Python and GDAL.

3) NGDC Biloxi, MS DEM

A 1/3 arc-second NAVD 88 DEM of Biloxi, Mississippi [Taylor, et al., 2007] was downloaded from the NGDC for use in the development of the Northern Gulf Coast DEM (Table 5 Figure 10). The DEM was developed for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The DEM was subsampled to 1 arc-second and converted to *xyz* format for gridding using GMT, Python and GDAL.

4) NGDC Mobile, AL DEM

A 1/3 arc-second NAVD 88 DEM of Mobile, Alabama [Amante, et al., 2009] was downloaded from the NGDC for use in the development of the Northern Gulf Coast DEM (Table 5 Figure 10). The DEM was developed for NOAA's CSDL through the ARRA of 2009 to evaluate the utility of *VDatum*, developed jointly by NOAA's OCS, NGS, and CO-OPS (http://vdatum.noaa.gov/). The DEM was subsampled to 1 arc-second and converted to *xyz* format for gridding using GMT, Python and GDAL.

5) NGDC Panama City, FL DEM

A 1/3 arc-second NAVD 88 DEM of Panama City, Florida [Amante, et al.,2009] was downloaded from the NGDC for use in the development of the Northern Gulf Coast DEM (Table 5 Figure 10). The DEM was developed for NOAA's CSDL through the ARRA of 2009 to evaluate the utility of *VDatum*, developed jointly by NOAA's OCS, NGS, and CO-OPS (http://vdatum.noaa.gov/). The DEM was subsampled to 1 arc-second and converted to *xyz* format for gridding using GMT, Python and GDAL.

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Northern Gulf Coast DEMs were originally referenced to several vertical datums including MLLW, MLW, MLG and NAVD 88. All datasets were transformed to NAVD 88 using *VDatum*. Where no *VDatum* coverage existed (Figure 14) datasets were transformed to NAVD 88 using the Northern Gulf Coast conversion grid (Section 4.3.1) which was derived from the existing *VDatum* project areas.

- **Bathymetric Data** All hydrographic surveys used in the compilation of the Northern Gulf Coast DEMs were transformed from MLLW, MLW or MLG to NAVD 88, using *VDatum*.
- **Topographic Data** All topographic datasets used in the compilation of the Northern Gulf Coast DEMs originated in NAVD 88 vertical datum. No further vertical transformations were required for these datasets.
- **Bathymetric–Topographic Data** Bathymetric-topographic datasets used in the compilation of the Northern Gulf Coast DEMs either originated in NAVD 88 vertical datum or were transformed from MHW to NAVD 88 using *VDatum*.

3.2.2 Horizontal datum transformations

Datasets used to build the Northern Gulf Coast DEMs were downloaded or received referenced to WGS 84 geographic, NAD 83 geographic, NAD 83 Louisiana State Plane (feet) and NAD 83 UTM Zone 16 or 15 N horizontal datums. The relationships and transformational equations between these horizontal datums are well established. Data were converted to a horizontal datum of NAD 83 geographic using Proj4 and *VDatum*.[7]

3.2.3 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the ascii *xyz* files were reviewed for consistency between datasets. Problems and errors were identified and resolved before proceeding with subsequent gridding steps.

[7] Proj4 (a free standard Unix filter function which converts geographic longitude and latitude coordinates into cartesian coordinates, $(\lambda, \phi) \rightarrow$ (x, y), by means of a wide variety of cartographic projection functions) was used to horizontally transform datasets that originated in a State Plane datum before vertical transformations were performed using *VDatum*, which did not support state plane transformations at the time of development.

4. STRUCTURED DEM DEVELOPMENT

4.1 Smoothing of bathymetric data

The NOS hydrographic survey data are generally sparse relative to the resolution of the 1 arc-second Northern Gulf Coast DEMs. This is especially true deep for water surveys in the Gulf of Mexico and shallow water surveys in lakes and bayous where data have point spacing up to 350 meters apart. In order to reduce the effect of artifacts created in the DEM by the low-resolution NOS datasets, and to provide effective interpolation in the deep water and into the coastal zone, a 1 arc-second pre-surface bathymetric grid (Figure 11) was generated using Generic Mapping Tools (GMT)[8]. The coastline elevation value was set at 0 meters to ensure a bathymetric surface below zero in areas where data are sparse or non-existent.

The point data were median-averaged using the GMT command 'blockmedian' to create a 1 arc-second grid 0.05 degrees (∼5%) larger than the Northern Gulf Coast gridding region. The GMT command 'surface' was then used to apply a tight spline tension to interpolate elevations for cells without data values. The GMT grid created by 'surface' was converted to an ESRI Arc ASCII grid file, and clipped to the final coastline (to eliminate data interpolation into land areas) using GDAL. The resulting surface was compared with original NOS soundings to ensure grid accuracy (Figure 12), and then exported as an *xyz* file for use in the final gridding process (Table 6).

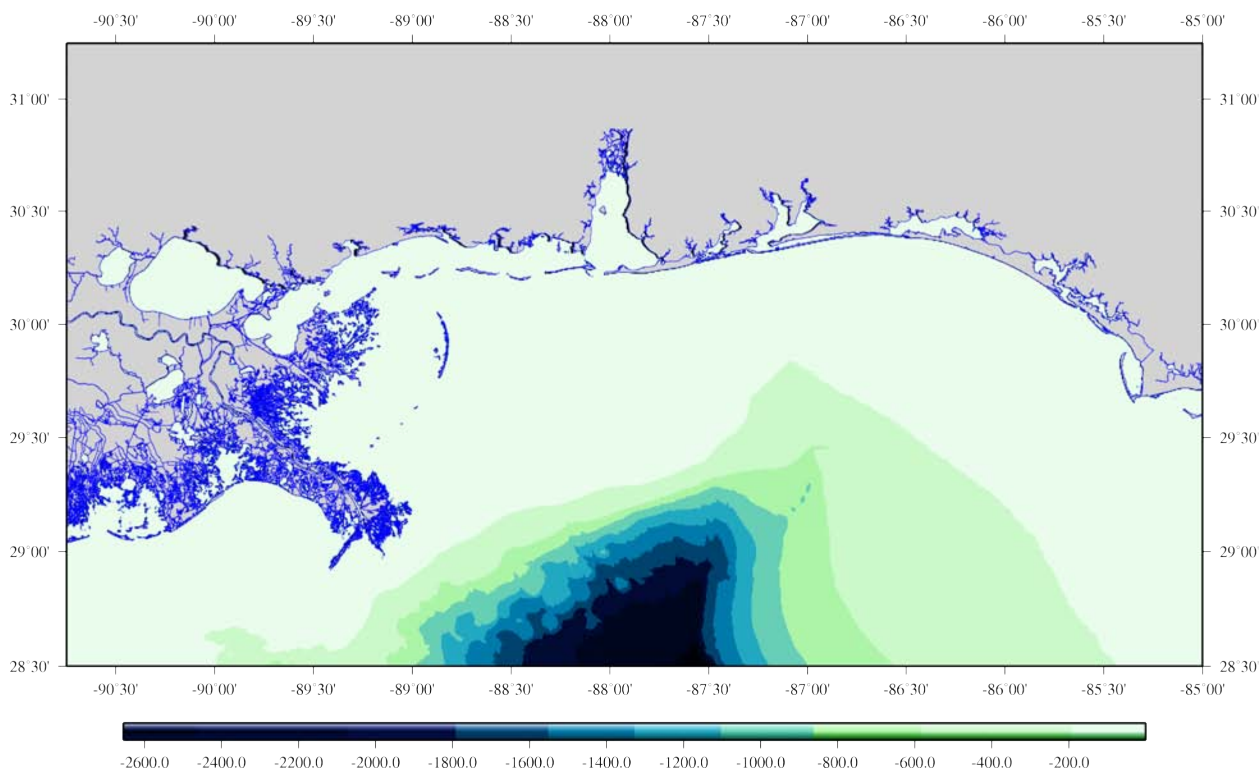


Figure 11. Pre-surface bathymetric grid of the Northern Gulf Coast

[8]GMT is an open source collection of ∼60 tools for manipulating geographic and Cartesian data sets (including filtering, trend fitting, gridding, projecting, etc.) and producing Encapsulated PostScript File (EPS) illustrations ranging from simple x-y plots via contour maps to artificially illuminated surfaces and 3-D perspective views. GMT supports ∼30 map projections and transformations and comes with support data such as GSHHS coastlines, rivers, and political boundaries. GMT is developed and maintained by Paul Wessel and Walter H. F. Smith with help from a global set of volunteers, and is supported by the National Science Foundation. It is released under the GNU General Public License. URL: http://gmt.soest.hawaii.edu/ [Extracted from GMT web site.]

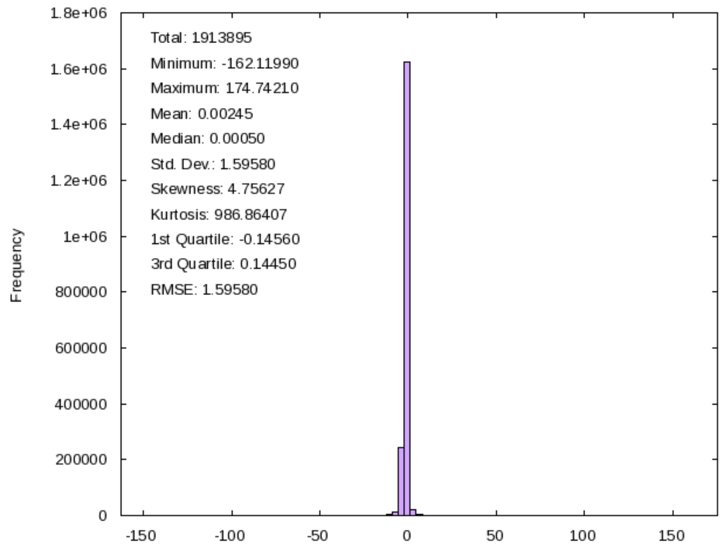


Figure 12. Histogram of the differences between the NOS hydrographic soundings and the Northern Gulf Coast bathymetric surface.

4.2 Building the NAVD 88 Structured DEM

MB-System[9] was used to create the 1 arc-second Northern Gulf Coast NAVD 88 DEM. The MB-System command 'mbgrid' was used to apply a tight spline tension to the *xyz* data, and interpolate values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 6. The resulting binary grid was converted to an Arc ASCII grid using the MB-System tool mbm_grd2arc to create the final 1 arc-second Northern Gulf Coast NAVD 88 DEM. Figure 13 illustrates cells in the DEM that have interpolated values (shown as white) versus data contributing to the cell value (shown as black).

Table 6. Data hierarchy used to assign gridding weight in MB-System

Dataset	***Relative Gridding Weight***
NGDC Northern Gulf Coast DEMs	75
NOS hydrographic surveys	75
USGS NED	60
FLDEM Franklin Co. contours	60
ENC hydrographic data	20
Pre-surfaced bathymetric grid	1

[9] MB-System is an open source software package for the processing and display of bathymetry and backscatter imagery data derived from multibeam, interferometry, and sidescan sonars. The source code for MB-System is freely available (for free) by anonymous ftp (point and access through these web pages). A complete description is provided in web pages accessed through the web site. MB-System was originally developed at the Lamont-Doherty Earth Observatory of Columbia University (L-DEO) and is now a collaborative effort between the Monterey Bay Aquarium Research Institute (MBARI) and L-DEO. The National Science Foundation has provided the primary support for MB-System development since 1993. The Packard Foundation has provided significant support through MBARI since 1998. Additional support has derived from SeaBeam Instruments (1994–1997), NOAA (2002–2004), and others. URL: http://www.ldeo.columbia.edu/res/pi/MB-System/ [Extracted from MB-System web site.]

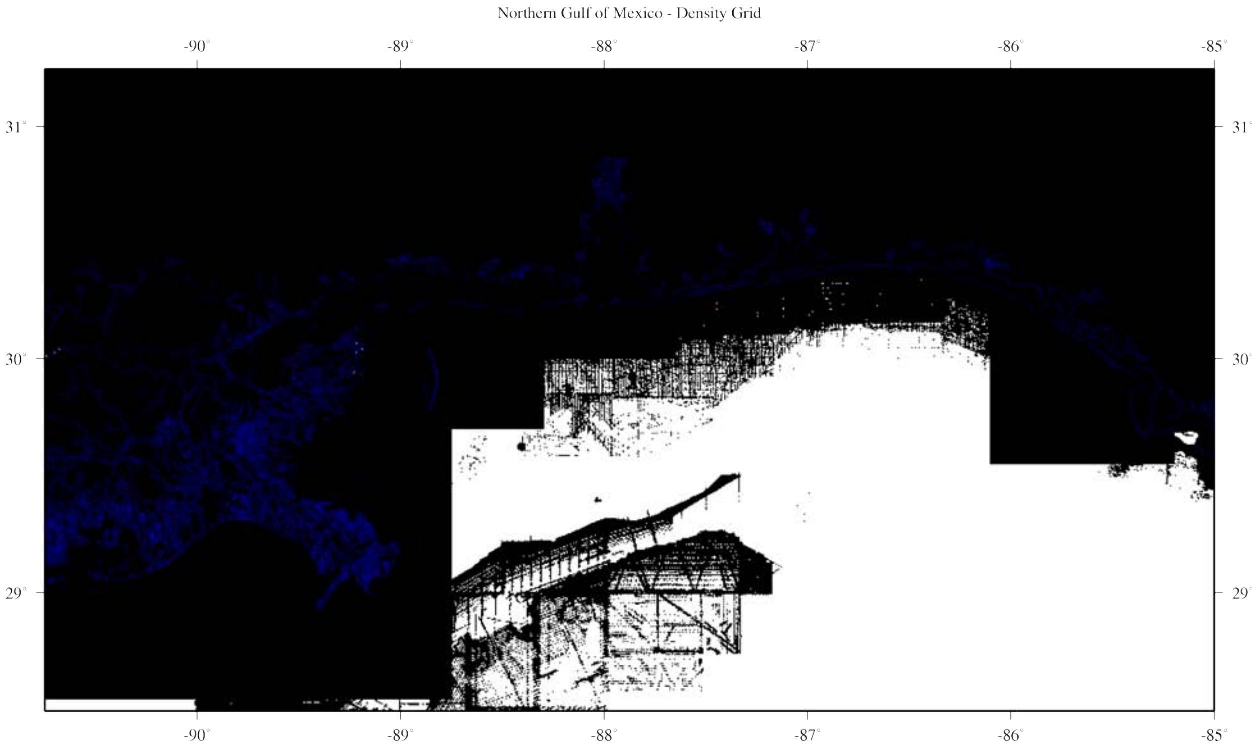


Figure 13. Data density of Northern Gulf Coast DEMs; Areas where source data were available are depicted in black; areas where grid interpolation was necessary are depicted in white. Areas of sparse data density are difficult to see at the current scale.

4.3 Building the MHW Structured DEM

The MHW DEM was created by adding the 'NAVD-88-to-MHW' conversion grid to the NAVD 88 DEM.

4.3.1 Developing the conversion grid

Using extents slightly larger (∼5%) than the Northern Gulf Coast project area, an initial *xyz* file was created that contained the coordinates of the four bounding vertices and midpoint of the larger extents. The elevation value at each of the points was set to zero. The GMT command 'surface' applied a tension spline to interpolate cell values making a zero-value 3 arc-second grid. This zero-grid was then converted to an intermediate *xyz* file using the GMT command 'grd2xyz'. Conversion values from NAVD-88-to-MHW at each *xyz* point were generated using *VDatum* and the null values were removed.

The median-averaged *xyz* file was then interpolated with the GMT command 'surface' to create the 1 arc-second 'NAVD-88-to-MHW' conversion grid with the extents of the Northern Gulf Coast project area. NGDC then used the GMT command 'surface' to interpolate values that represented the differences between the two datums onshore to the DEM extents (Figure 15) and offshore areas where no *VDatum* project areas were available (Figure 14).

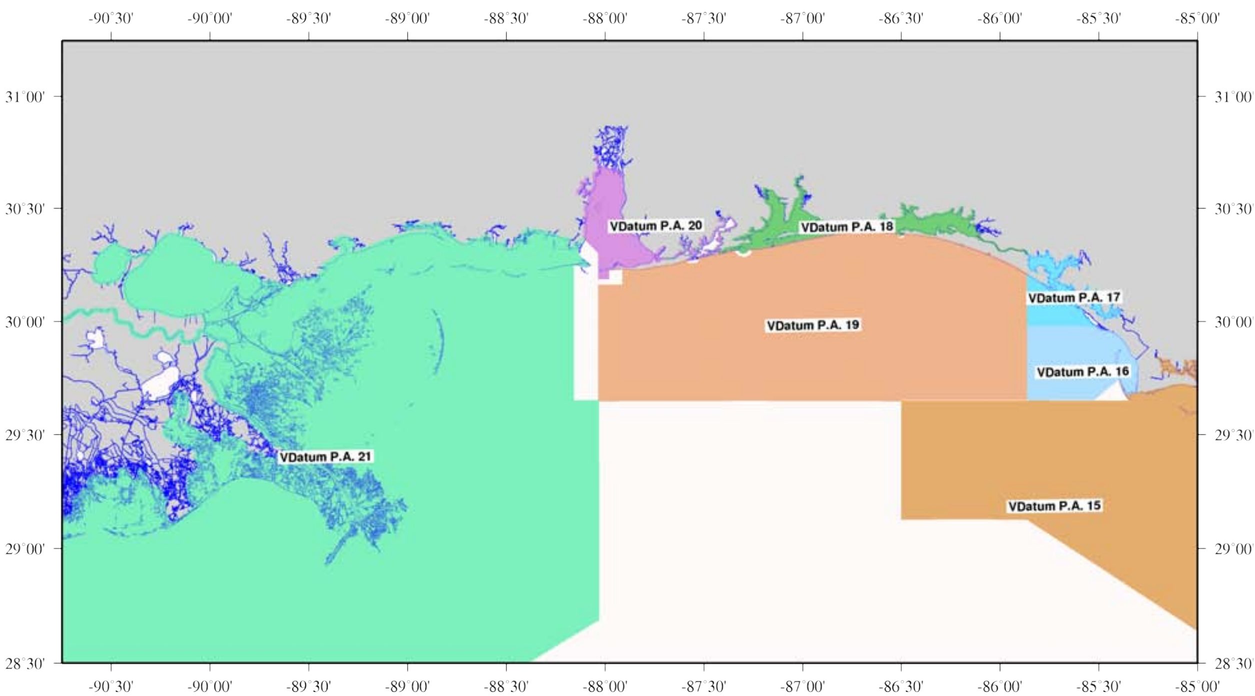


Figure 14. Available VDatum Project Areas (P.A.) in the Northern Gulf Coast DEM region.

4.3.2 Assessing the accuracy of conversion grid

The 'NAVD-88-to-MHW' conversion grid was assessed using the NOS survey data. For testing of this methodology, the NOS hydrographic survey data were transformed from MLW and MLLW to NAVD 88 using *VDatum*. The resultant *xyz* files were filtered to remove any null values and then were merged together to form a single *xyz* file of the NOS hydrographic survey data with a vertical datum of NAVD 88. A second *xyz* file of NOS data was created with a vertical datum of MHW using the same method. Elevation differences between the MHW and NAVD 88 *xyz* files were computed.

To verify the conversion grid methodology, the difference *xyz* file was used to generate a histogram using

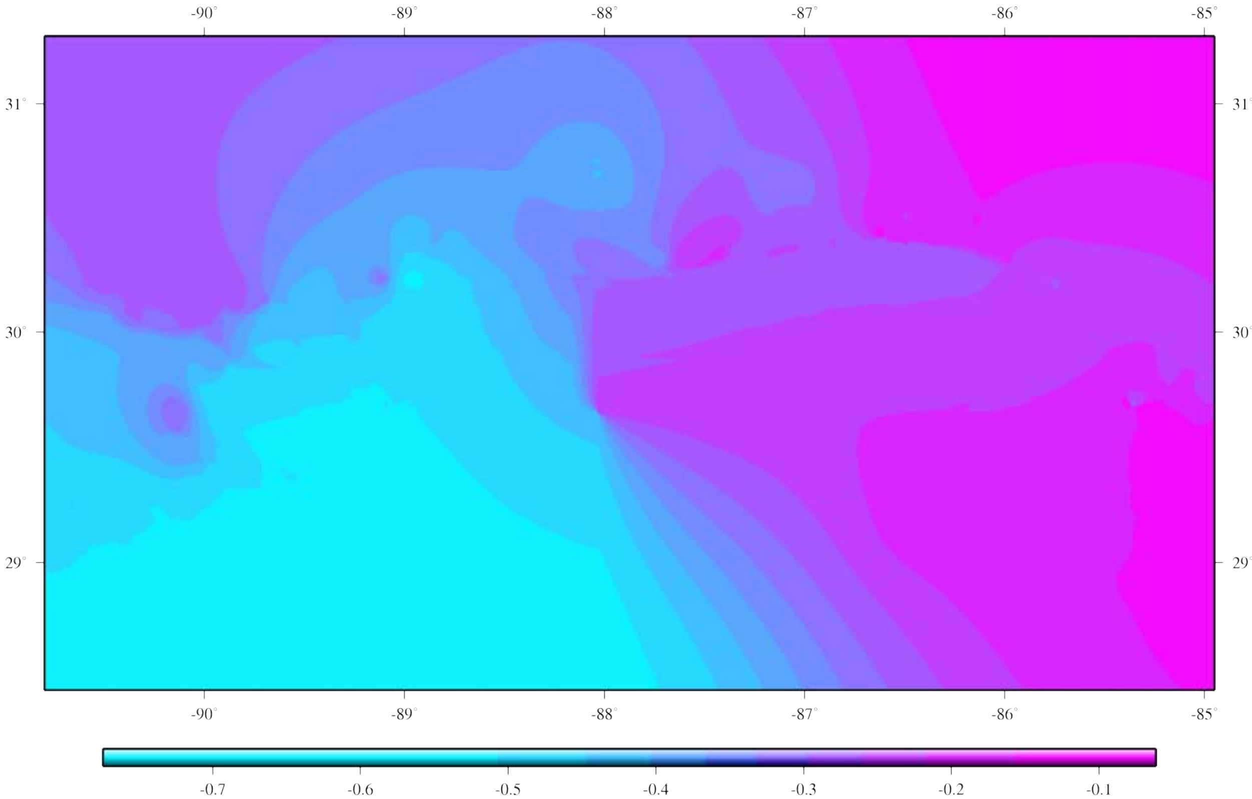


Figure 15. Elevation conversion values of 'NAVD-88-to-MHW' conversion grid derived from VDatum. Values equal the difference between NAVD 88 and MHW.

Gnuplot[10] to evaluate the performance of the 1 arc-second conversion grid by comparing 'NAVD-88-to-MHW' conversion grid to the combined difference *xyz* files from the *VDatum* project area (Fig. 16). Errors in the vertical datum conversion method will reside for the most part in the 'NAVD-88-to-MHW' conversion grid, as the topographic data are already referenced to NAVD 88. Errors in the source datasets will require rebuilding just the NAVD 88 DEM.

4.3.3 Creating the MHW Structured DEM

Once the NAVD 88 structured DEM was completed and assessed for errors, the conversion grid was added to it using the GMT command 'grdmath'. The resulting MHW structured DEM was reviewed and assessed using RNCs, USGS topographic maps, and ESRI World 2D imagery.

[10]Gnuplot is an open-source command-driven interactive function plotting program. It can be used to plot functions and data points in both two- and three-dimensional plots in many different formats. It is designed primarily for the visual display of scientific data.

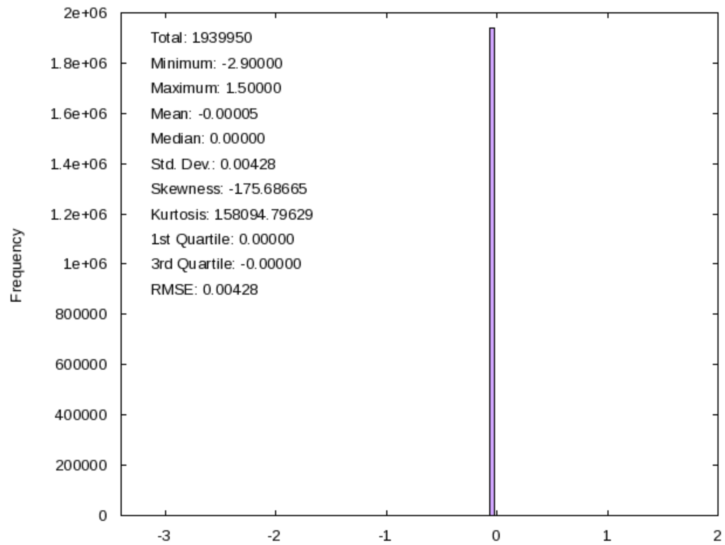


Figure 16. Histogram of the differences between the conversion grid and xyz difference files using NOS hydrographic survey data.

4.4 Quality Assessment of the Structured DEMs

4.4.1 Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Northern Gulf Coast DEMs are dependent upon the datasets used to determine corresponding DEM cell values and the cell size of the DEM. The horizontal accuracy is 10 meters where topographic lidar datasets contribute to the DEM cell value. The horizontal accuracy is 0.75 meters at 1 sigma where only bathymetric–topographic lidar-derived data contributes to the DEM cell value. Bathymetric features are resolved only to within a few tens of meters in deep-water areas. Shallow, near-coastal regions, rivers, and harbor surveys have an accuracy approaching that of sub aerial topographic features. Positional accuracy is limited by: the sparseness of deep-water soundings; potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys; and by the morphologic change that occurs in this dynamic region.

4.4.2 Vertical accuracy

Vertical accuracy of the Northern Gulf Coast DEMs are also highly dependent upon the source datasets contributing to DEM cell values. Topographic lidar has an estimated RMSE of 13.9 to 20 cm. Bathymetric–topographic lidar-derived data have a vertical accuracy of 0.20 meters at 1 sigma. Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth. Those values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations.

4.4.3 Slope maps and 3D perspectives

GMT was used to generate a slope grid from the Northern Gulf Coast NAVD 88 DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Figure 17). The DEM was transformed to UTM Zone 15 North coordinates (horizontal units in meters) in GDAL for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of the UTM-transformed DEM was accomplished using QTModeler. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Figure 18 shows a perspective view image of the 1 arc-second Northern Gulf Coast NAVD 88 DEM in its final version.

4.4.4 Comparison with National Geodetic Survey geodetic monuments

The elevations of 80948 NOAA NGS geodetic monuments (Figure 19a) were extracted from online shapefiles of NGS Geodetic monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD 83 (typically sub-mm accuracy) and elevations in NAVD 88 (in meters). Monument elevations were compared with elevations of the Northern Gulf Coast NAVD 88 DEM. Differences between the DEM elevations and the NGS geodetic monument elevations range from -109.5 to 77.5 meters, with the majority of them being within +/-1 meter (Figure 19b). Negative values indicate that the monument elevation is less than the DEM elevation. After examination, it was determined that those monuments with the largest deviations do not represent ground surface as they are located on top of an observation tower, light house, at the apex of other structures, or are receded into the ground.

4.4.5 Comparison with source data files

To ensure grid accuracy, the Northern Gulf Coast NAVD 88 DEM was compared to source data files. All bathymetric and topographic source data were compared to the DEM using Python, GDAL and Gnuplot. Histograms of the differences between individual datasets and the DEM are shown in Figure 20. The largest differences between source datasets and the DEM resulted from the averaging of multiple topographic source datasets where data coverage overlapped, particularly in regions of steep slopes.

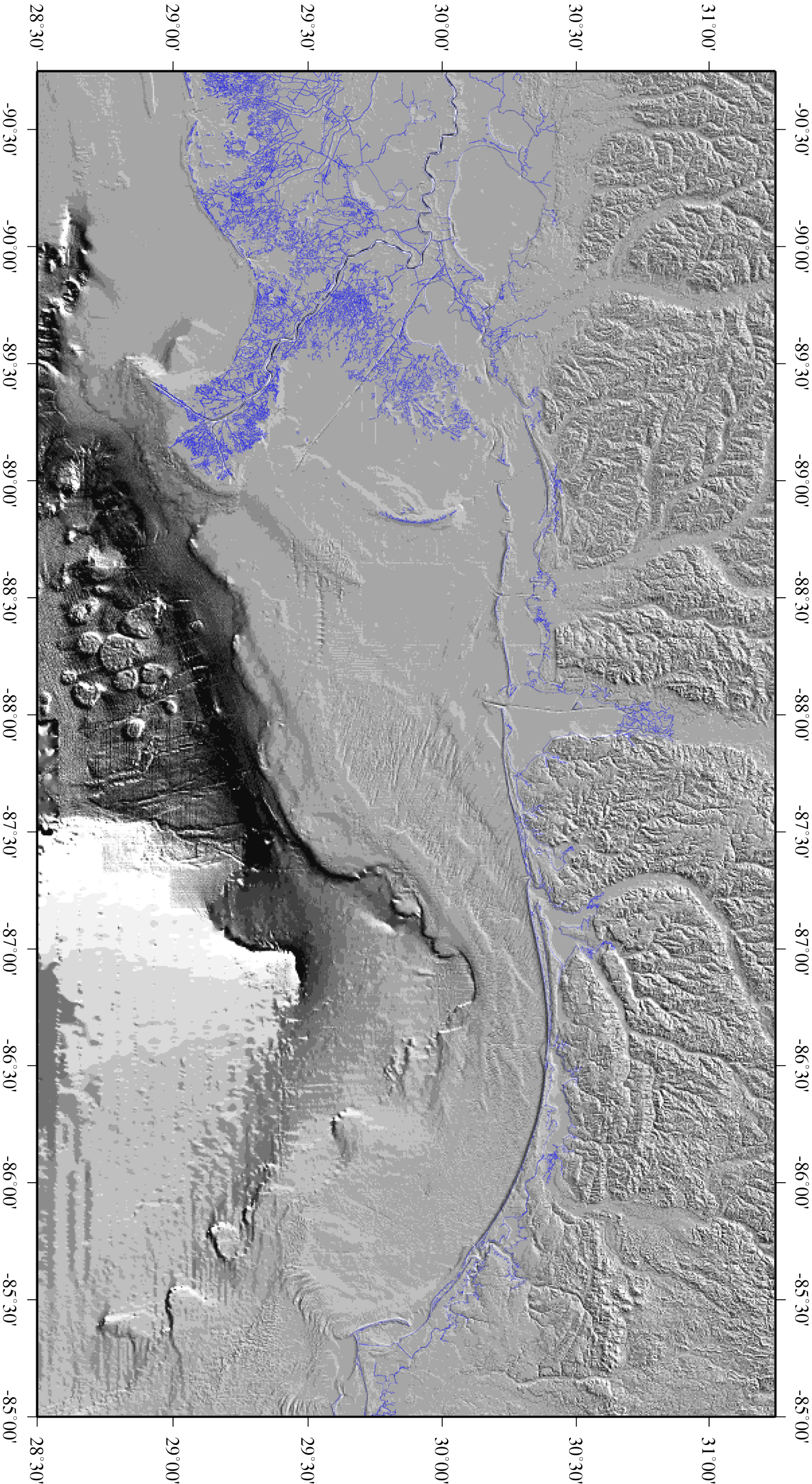


Figure 17. Slope map of the Northern Gulf Coast NAVD 88 DEM. Flat-lying slopes are white; dark shading denotes steep slopes. The coastline is drawn in blue

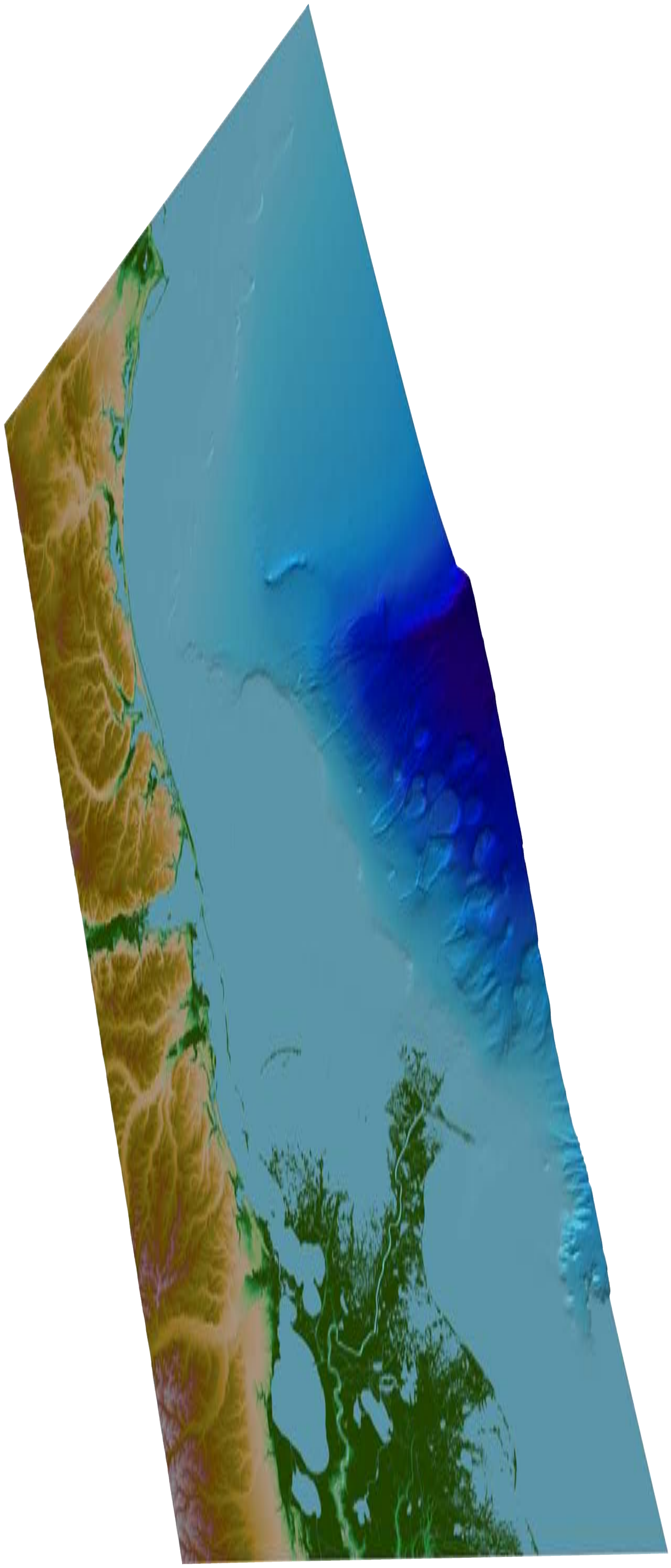
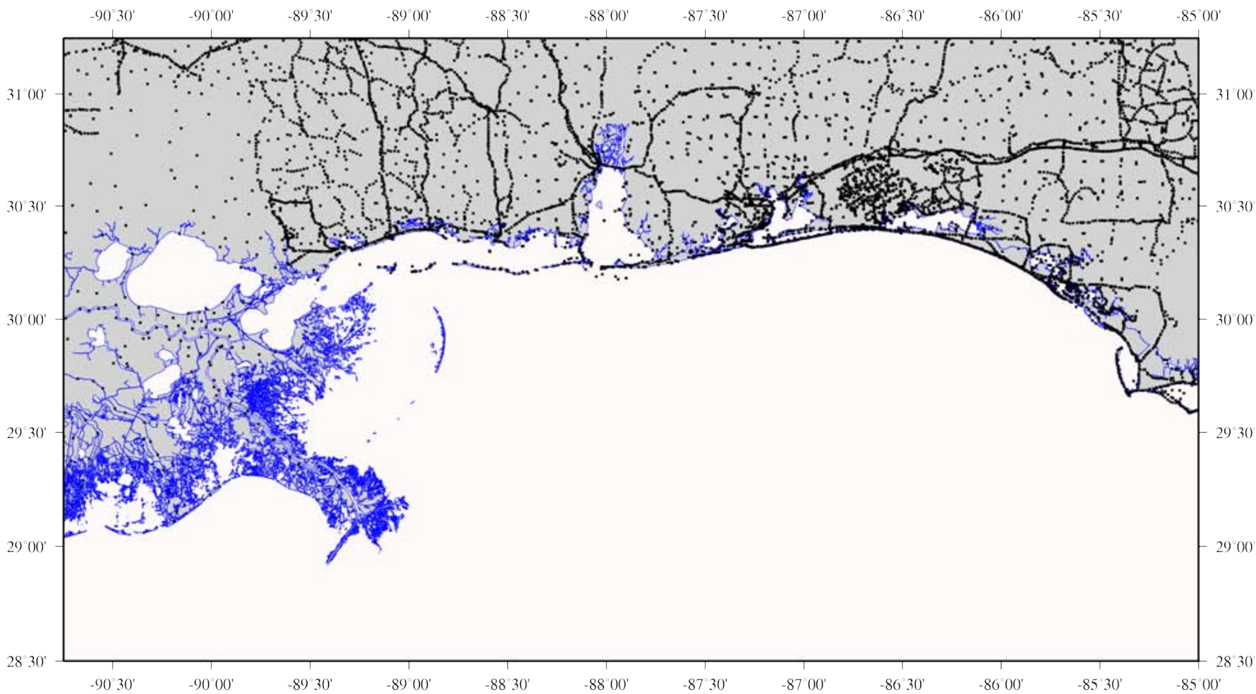
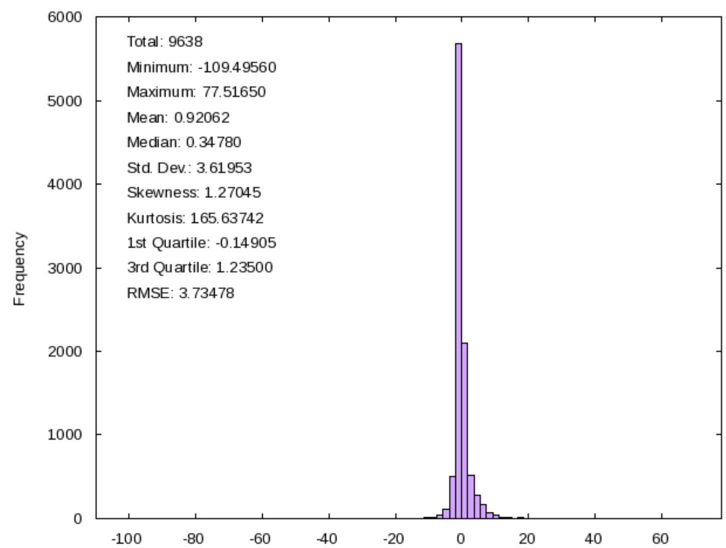


Figure 18. Perspective view from the southwest of the Northern Gulf Coast NAVD 88 DEM. Fifteen times vertical exaggeration.

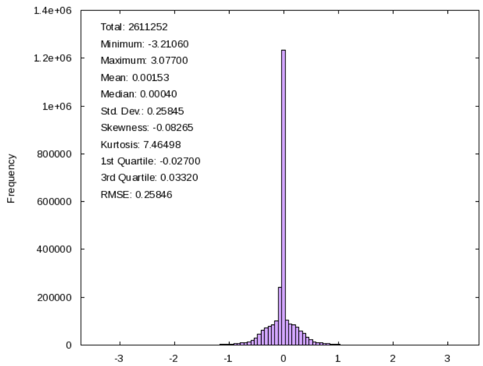


(a) *Locations of NGS monuments used in the evaluation of the Northern Gulf Coast DEMs.*

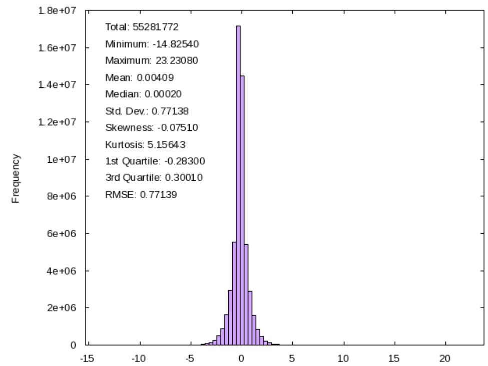


(b) *Histogram of the differences between the NGS monument elevation values and the Northern Gulf Coast DEM*

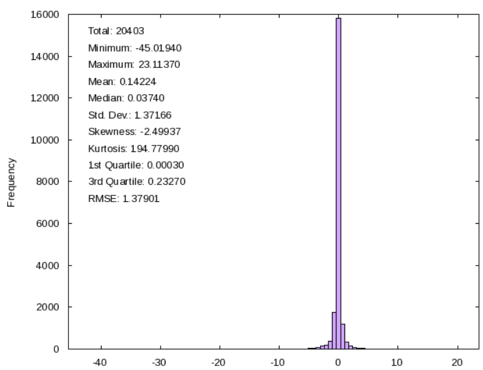
Figure 19. Comparison with NGS geodetic monuments, locations and histogram.



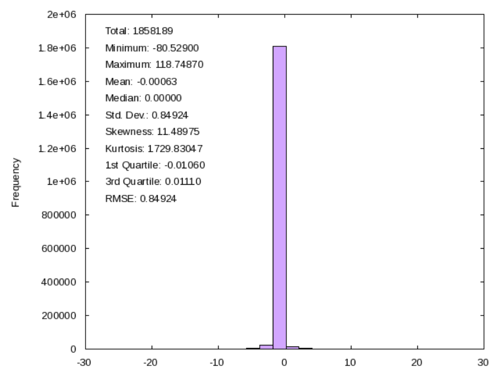
(a) *Histogram of the differences between the FDEM lidar dataset and the Northern Gulf Coast NAVD 88 DEM*



(b) *Histogram of the differences between the NED 1 DEM dataset and the Northern Gulf Coast NAVD 88 DEM*



(c) *Histogram of the differences between the ENC hydrographic dataset and the Northern Gulf Coast NAVD 88 DEM*



(d) *Histogram of the differences between the NOS hydrographic dataset and the Northern Gulf Coast NAVD 88 DEM*

Figure 20. Hisograms of the differences between individual datasets and the Northern Gulf Coast NAVD 88 DEM.

5. Summary and Conclusions

Two bathymetric–topographic digital elevation models of the Northern Gulf Coast region, with cell spacing of 1 arc-second, and vertical datums of NAVD 88 and MHW, respectively, were developed for CSDL through the ARRA of 2009. The DEMs were developed to validate the utility of NOAA's OCS, NGS, and CO-OPS jointly developed *VDatum* tool and will be used for storm surge inundation and sea level rise modeling. The best available digital data from U.S. federal, state and local agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI ArcGIS, GMT, MB-System, QT Modeler, GDAL, Proj4 and Gnuplot software. *VDatum* was utilized throughout the development of the Northern Gulf Coast DEMs to transform data to common vertical datums. Furthermore, NGDC developed a conversion grid derived from the *VDatum* project areas that transformed the Northern Gulf Coast NAVD 88 DEM to MHW, and allowed for vertical transformation of source datasets where no *VDatum* coverage area existed.

Recommendations to improve the Northern Gulf Coast DEMs, based on NGDCâĂŹs research and analysis, are listed below:

- Conduct topographic lidar surveys for all near-shore regions.
- Conduct NOS hydrographic surveys in hydrographic data gaps and in estuary bays and rivers.
- Conduct topographic surveys of coastal marsh-lands.

6. Acknowledgements

The creation of the Northern Gulf Coast DEMs was funded by the ARRA of 2009. The authors thank Jay Ratcliff of the USACE for supplying otherwise unavailable bathymetric surveys. The authors also thank Cuong Hoang and Maureen Kenny (NOAA CSDL) for providing NGDC with the NOS survey non-superceded database.

7. References

Amante, C.J., Love, M.R., Eakins, B.W., Taylor, L.A., 2009: Digital Elevation Models of Mobile, Alabama: Procedures, Data Sources and Analysis.

Amante, C.J., Love, M.R., Eakins, B.W., Taylor, L.A., 2009: Digital Elevation Models of Panama City, Florida: Procedures, Data Sources and Analysis.

Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A, 2003. Federal Emergency Management Agency, Flood Hazard Mapping Program.

Love, M.R., Amante, C.J., Eakins, B.W., Taylor, L.A., 2009: Digital Elevation Models of New Orleans, Louisiana: Procedures, Data Sources and Analysis.

Love, M.R., Amante, C.J., Eakins, B.W., Taylor, L.A., 2010: Digital Elevation Models of Southern Louisiana: Procedures, Data Sources and Analysis.

Taylor, L.A., Eakins, B.W., Carignan, K.S., Warnken, R.R., Sazonova, T., Schoolcraft, D.C., 2007: Digital Elevation Models of Biloxi, Mississippi: Procedures, Data Sources and Analysis.

8. DATA PROCESSING SOFTWARE

ArcGIS 9.3 - developed and liscensed by ESRI, Redlands, California, http://www.esri.com

ESRI World Imagery - ESRI ArcGIS Resource Centers, http://www.esri.com

GEODAS v. 5 - Geophysical Data System, free software developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas

GMT v. 4.1.4 - Generic Mapping Tools, free software developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu

MB-System v. 5.1.0 - free software developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System

Quick Terrain Modeler v. 6.0.1 - lidar processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com

GDAL v. 1.7.1 - Geographic Data Abstraction Library is a translator library maintained by Frank Warmerdam, http://gdal.org

Proj4 v. 4.7.0 - free software developed by Gerald Evenden and maintained by Frank Warmerdam, http://trac.osgeo.org/proj/

VDatum v. 2.3 developed and maintained by NOAAs National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS), http://vdatum.noaa.gov/

Appendix A. NOS Hydrographic Surveys

Table A-1. NOS Hydrographic datasets used in building the Northern Gulf Coast DEMs

Survey ID	*Year*	*Original Vertical Datum*	*Scale/Vertical Accuracy*	*Provided Horizontal Datum*
H01184	1873	Undetermined	1:40,000	Undetermined
H01991	1876	Undetermined	1:4800	Undetermined
H01909	1888	Undetermined	1:5,000	Undetermined
H01910	1888	Undetermined	1:5,000	Undetermined
H01911	1888	Undetermined	1:5,000	Undetermined
H01912	1888	Undetermined	1:5,000	Undetermined
H01913	1888	Undetermined	1:5,000	Undetermined
H01914	1888	Undetermined	1:5,000	Undetermined
H01915	1888	Undetermined	1:5,000	Undetermined
H01916	1888	Undetermined	1:5,000	Undetermined
H01917	1888	Undetermined	1:5,000	Undetermined
H02072	1891	Undetermined	1:20,000	Undetermined
H02295	1897	Undetermined	1:20,000	Undetermined
H02341	1898	Undetermined	1:20,000	Undetermined
H02342	1898	Undetermined	1:20,000	Undetermined
H02380	1899	Undetermined	1:20,000	Undetermined
H02381	1899	Undetermined	1:20,000	Undetermined
H04000	1917	MLW	1:40,000	Undetermined
H04021	1917	MLW	1:40,000	Undetermined
H03961	1917	Undetermined	1:40,000	Undetermined
H04139	1919	Undetermined	1:80,000	Undetermined
H04171	1920	MLW	1:80,000	Undetermined
H04212	1921	Undetermined	1:80,000	Undetermined
H04219	1922	Undetermined	1:80,000	Undetermined
H04223	1922	Undetermined	1:80,000	Undetermined
H05024	1930	Undetermined	10,000	Undetermined

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H05033	1930	Undetermined	20,000	Undetermined
H05115	1930	Undetermined	40,000	Undetermined
H05113	1931	Undetermined	80,000	Undetermined
H05491	1933	Undetermined	20,000	Undetermined
H05667	1934	Undetermined	10,000	Undetermined
H05668	1934	Undetermined	10,000	Undetermined
H05723	1934	Undetermined	10,000	Undetermined
H05478	1934	Undetermined	20,000	Undetermined
H05479	1934	Undetermined	20,000	Undetermined
H05480	1934	Undetermined	20,000	Undetermined
H05481	1934	Undetermined	20,000	Undetermined
H05482	1934	Undetermined	20,000	Undetermined
H05490	1934	Undetermined	20,000	Undetermined
H05492	1934	Undetermined	20,000	Undetermined
H05493	1934	Undetermined	20,000	Undetermined
H05494	1934	Undetermined	20,000	Undetermined
H05495	1934	Undetermined	20,000	Undetermined
H05496	1934	Undetermined	20,000	Undetermined
H05497	1934	Undetermined	20,000	Undetermined
H05537	1934	Undetermined	20,000	Undetermined
H05539	1934	Undetermined	20,000	Undetermined
H05541	1934	Undetermined	20,000	Undetermined
H05669	1935	Undetermined	10,000	Undetermined
H05705	1935	Undetermined	10,000	Undetermined
H05706	1935	Undetermined	10,000	Undetermined
H05707	1935	Undetermined	10,000	Undetermined
H05729	1935	Undetermined	10,000	Undetermined
H05780	1935	Undetermined	10,000	Undetermined

Table A-1 – Continued

Survey ID	*Year*	*Original Vertical Datum*	*Scale/Vertical Accuracy*	*Provided Horizontal Datum*
H05781	1935	Undetermined	10,000	Undetermined
H05782	1935	Undetermined	10,000	Undetermined
H05783	1935	Undetermined	10,000	Undetermined
H05791	1935	Undetermined	10,000	Undetermined
H05792	1935	Undetermined	10,000	Undetermined
H05793	1935	Undetermined	10,000	Undetermined
H05796	1935	Undetermined	10,000	Undetermined
H05797	1935	Undetermined	10,000	Undetermined
H05805	1935	Undetermined	10,000	Undetermined
H05806	1935	Undetermined	10,000	Undetermined
H05817	1935	Undetermined	10,000	Undetermined
H05823	1935	Undetermined	10,000	Undetermined
H05538	1935	Undetermined	20,000	Undetermined
H05730	1935	Undetermined	20,000	Undetermined
H05794	1935	Undetermined	20,000	Undetermined
H05812	1935	Undetermined	20,000	Undetermined
H05818	1935	Undetermined	20,000	Undetermined
H05822	1935	Undetermined	20,000	Undetermined
H05833	1935	Undetermined	20,000	Undetermined
H05835	1935	Undetermined	20,000	Undetermined
H05836	1935	Undetermined	20,000	Undetermined
H05869	1935	Undetermined	20,000	Undetermined
H06172	1936	Undetermined	20,000	Undetermined
H06174	1936	Undetermined	20,000	Undetermined
H06154	1936	Undetermined	40,000	Undetermined
H06155	1936	Undetermined	40,000	Undetermined
H06156	1936	Undetermined	40,000	Undetermined
H06157	1936	Undetermined	40,000	Undetermined

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H06173	1936	Undetermined	40,000	Undetermined
H06184	1936	Undetermined	80,000	Undetermined
H06185	1936	Undetermined	80,000	Undetermined
H06448	1939	Undetermined	10,000	Undetermined
H06449	1939	Undetermined	10,000	Undetermined
H06450	1939	Undetermined	10,000	Undetermined
H06451	1939	Undetermined	10,000	Undetermined
H06452	1939	Undetermined	10,000	Undetermined
H06492	1939	Undetermined	20,000	Undetermined
H06513	1939	Undetermined	20,000	Undetermined
H06633	1940	Undetermined	10,000	Undetermined
H06547	1940	Undetermined	160,000	Undetermined
H06548	1940	Undetermined	160,000	Undetermined
H06634	1940	Undetermined	20,000	Undetermined
H06635	1940	Undetermined	20,000	Undetermined
H06636	1940	Undetermined	20,000	Undetermined
H06637	1940	Undetermined	20,000	Undetermined
H06638	1940	Undetermined	20,000	Undetermined
H06551	1940	Undetermined	40,000	Undetermined
H06552	1940	Undetermined	40,000	Undetermined
H06553	1940	Undetermined	40,000	Undetermined
H06554	1940	Undetermined	40,000	Undetermined
H06555	1940	Undetermined	40,000	Undetermined
H06549	1940	Undetermined	80,000	Undetermined
H06550	1940	Undetermined	80,000	Undetermined
H06656	1940	Undetermined	80,000	Undetermined
H06685	1941	Undetermined	20,000	Undetermined
H06686	1941	Undetermined	20,000	Undetermined

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H06693	1941	Undetermined	20,000	Undetermined
H06694	1941	Undetermined	20,000	Undetermined
H06687	1941	Undetermined	40,000	Undetermined
H06688	1941	Undetermined	40,000	Undetermined
H06689	1941	Undetermined	40,000	Undetermined
H06690	1941	Undetermined	40,000	Undetermined
H06691	1941	Undetermined	80,000	Undetermined
H06692	1941	Undetermined	80,000	Undetermined
H06786	1942	Undetermined	20,000	Undetermined
H06787	1942	Undetermined	20,000	Undetermined
H06788	1942	Undetermined	20,000	Undetermined
H06784	1942	Undetermined	40,000	Undetermined
H06785	1942	Undetermined	40,000	Undetermined
H06789	1943	Undetermined	20,000	Undetermined
H07173	1947	Undetermined	10,000	Undetermined
H07603	1947	Undetermined	200,000	Undetermined
H07631	1947	Undetermined	40,000	Undetermined
H07632	1947	Undetermined	40,000	Undetermined
H07633	1947	Undetermined	40,000	Undetermined
F00077	1948	MLW	40,000	North American Datum 1927
H07723	1948	Undetermined	1:100,000	Undetermined
H07604	1948	Undetermined	200,000	Undetermined
H07679	1949	Undetermined	100,000	Undetermined
H08524	1960	Undetermined	10,000	Undetermined
H08525	1960	Undetermined	10,000	Undetermined
H08526	1960	Undetermined	10,000	Undetermined
H08560	1960	Undetermined	10,000	Undetermined

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H08561	1960	Undetermined	10,000	Undetermined
H08562	1960	Undetermined	10,000	Undetermined
H08573	1960	Undetermined	10,000	Undetermined
H08574	1960	Undetermined	10,000	Undetermined
H08575	1960	Undetermined	10,000	Undetermined
H08592	1960	Undetermined	10,000	Undetermined
H08563	1960	Undetermined	20,000	Undetermined
H08586	1961	Undetermined	10,000	Undetermined
H08587	1961	Undetermined	10,000	Undetermined
H08588	1961	Undetermined	10,000	Undetermined
H08589	1961	Undetermined	10,000	Undetermined
H08590	1961	Undetermined	10,000	Undetermined
H08591	1961	Undetermined	10,000	Undetermined
H08633	1961	Undetermined	10,000	Undetermined
H08634	1961	Undetermined	10,000	Undetermined
H08635	1961	Undetermined	10,000	Undetermined
H08636	1961	Undetermined	10,000	Undetermined
H08642	1961	Undetermined	10,000	Undetermined
H08643	1961	Undetermined	10,000	Undetermined
H08644	1961	Undetermined	10,000	Undetermined
H08645	1961	Undetermined	10,000	Undetermined
H08646	1961	Undetermined	10,000	Undetermined
H08647	1961	Undetermined	20,000	Undetermined
H08648	1961	Undetermined	20,000	Undetermined
H08584	1961	Undetermined	5,000	Undetermined
H08585	1961	Undetermined	5,000	Undetermined
H08649	1962	Undetermined	10,000	Undetermined
H08650	1962	Undetermined	10,000	Undetermined

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H08651	1962	Undetermined	10,000	Undetermined
H08652	1962	Undetermined	10,000	Undetermined
H08923	1966	MLW	10,000	North American Datum 1927
H08922	1966	MLW	10,000	Undetermined
H08925	1967	MLW	10,000	North American Datum 1927
H08924	1967	MLW	20,000	Undetermined
H08970	1968	MLW	10,000	North American Datum 1927
H08971	1968	MLW	20,000	Undetermined
H09004	1968	Undetermined	20,000	Undetermined
H09156	1970	MLW	10,000	North American Datum 1927
H09177	1970	MLW	10,000	North American Datum 1927
H09109	1970	MLW	20,000	North American Datum 1927
H09118	1970	MLW	20,000	North American Datum 1927
H09028	1970	Undetermined	20,000	Undetermined
H09199	1971	MLW	10,000	North American Datum 1927
H09262	1971	MLW	10,000	North American Datum 1927
H09263	1971	MLW	10,000	North American Datum 1927
H09200	1971	MLW	20,000	North American Datum 1927
H09261	1971	MLW	20,000	North American Datum 1927
H09279	1972	MLW	10,000	North American Datum 1927
H09347	1972	Unknown	20,000	North American Datum 1927
H09354	1973	MLW	20,000	North American Datum 1927

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H09466	1974	MLW	40,000	North American Datum 1927
H09734	1977	GCLWD	20,000	North American Datum 1927
H09735	1977	GCLWD	20000	North American Datum 1927
H09761	1978	GCLWD	20,000	North American Datum 1927
H09781	1978	GCLWD	20,000	North American Datum 1927
H09797	1978	GCLWD	20,000	North American Datum 1927
H09803	1978	GCLWD	20,000	North American Datum 1927
H09755	1978	GCLWD	20000	North American Datum 1927
H09786	1978	GCLWD	40,000	North American Datum 1927
H09804	1979	GCLWD	20,000	North American Datum 1927
H09861	1979	GCLWD	20000	North American Datum 1927
H09798	1979	GCLWD	40,000	North American Datum 1927
H09832	1979	GCLWD	50,000	North American Datum 1927
H09846	1979	MLLW	40000	North American Datum 1927
H09915	1980	GCLWD	20000	North American Datum 1927
H09883	1980	GCLWD	40000	North American Datum 1927
H09924	1980	MLLW	10000	North American Datum 1927
H09925	1980	MLLW	10000	North American Datum 1927
H09989	1981	MLLW	10,000	North American Datum 1927
H09968	1981	MLLW	10000	North American Datum 1927

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H09928	1981	MLLW	20,000	North American Datum 1927
H09943	1981	MLLW	20,000	North American Datum 1927
H09971	1981	MLLW	20,000	North American Datum 1927
H09954	1981	MLLW	40,000	North American Datum 1927
H09996	1982	MLLW	10,000	North American Datum 1927
H09995	1982	MLLW	10000	North American Datum 1927
H10005	1982	MLLW	10000	North American Datum 1927
H10069	1982	MLLW	10000	North American Datum 1927
H10041	1982	MLLW	20000	North American Datum 1927
H10001	1982	MLLW	40,000	North American Datum 1927
H10053	1982	MLLW	40000	North American Datum 1927
H10122	1983	MLLW	10,000	North American Datum 1927
H10114	1983	MLLW	20000	North American Datum 1927
H10113	1983	MLLW	40000	North American Datum 1927
H10166	1984	MLLW	10000	North American Datum 1927
H10168	1984	MLLW	10000	North American Datum 1927
D00078	1984	Undetermined	40000	Undetermined
D00065	1984	Undetermined	80000	Undetermined
H10170	1985	MLLW	10,000	North American Datum 1927
H10172	1985	MLLW	10000	North American Datum 1927
H10207	1985	MLLW	10000	North American Datum 1927

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H10179	1985	MLLW	20000	North American Datum 1927
H10208	1985	MLLW	20000	North American Datum 1927
H10180	1985	MLLW	40000	North American Datum 1927
H10206	1985	MLLW	40000	North American Datum 1927
H10209	1986	MLLW	10000	North American Datum 1927
H10210	1986	MLLW	10000	North American Datum 1927
H10235	1986	MLLW	10000	North American Datum 1927
H10226	1986	MLLW	20000	North American Datum 1927
F00288	1986	MLLW	40000	North American Datum 1927
H10236	1987	MLLW	10000	North American Datum 1927
H10237	1987	MLLW	10000	North American Datum 1927
H10259	1987	MLLW	10000	North American Datum 1927
H10260	1987	MLLW	10000	North American Datum 1927
H10262	1987	MLLW	10000	North American Datum 1927
H10247	1987	MLLW	20000	North American Datum 1927
H10261	1987	MLLW	20000	North American Datum 1927
B00136	1988	MHW	50,000	North American Datum 1983
H10266	1988	MLLW	10000	North American Datum 1927
H10267	1988	MLLW	10000	North American Datum 1927
H10292	1988	MLLW	10000	North American Datum 1983

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
F00314	1988	MLLW	20000	North American Datum 1983
F00315	1988	MLLW	20000	North American Datum 1983
B00122	1988	MLLW	50,000	North American Datum 1983
B00124	1988	MLLW	50,000	North American Datum 1983
B00125	1988	MLLW	50,000	North American Datum 1983
B00130	1988	MLLW	50,000	North American Datum 1983
B00133	1988	MLLW	50,000	North American Datum 1983
B00138	1988	MLLW	50,000	North American Datum 1983
B00139	1988	MLLW	50,000	North American Datum 1983
D00100	1988	Undetermined	10000	Undetermined
D00077	1988	Undetermined	20000	Undetermined
D00079	1988	Undetermined	20000	Undetermined
H10294	1989	MLLW	10000	North American Datum 1927
F00324	1989	MLLW	20000	North American Datum 1983
F00329	1989	MLLW	20000	North American Datum 1983
F00335	1989	MLLW	20000	North American Datum 1983
B00183	1989	MLLW	50,000	North American Datum 1983
B00189	1989	MLLW	50,000	North American Datum 1983
B00190	1989	MLLW	50,000	North American Datum 1983
B00191	1989	MLLW	50,000	North American Datum 1983
B00193	1989	MLLW	50,000	North American Datum 1983

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
B00194	1989	MLLW	50,000	North American Datum 1983
B00197	1989	MLLW	50,000	North American Datum 1983
B00198	1989	MLLW	50,000	North American Datum 1983
B00199	1989	MLLW	50,000	North American Datum 1983
B00258	1990	MLLW	50,000	North American Datum 1983
B00259	1990	MLLW	50,000	North American Datum 1983
H10387	1991	MLLW	10000	North American Datum 1983
H10394	1991	MLLW	10000	North American Datum 1983
H10403	1991	MLLW	10000	North American Datum 1983
H10375	1991	MLLW	20000	North American Datum 1983
H10393	1991	MLLW	20000	North American Datum 1983
B00290	1991	MLLW	50,000	North American Datum 1983
B00291	1991	MLLW	50,000	North American Datum 1983
B00294	1991	MLLW	50,000	North American Datum 1983
B00295	1991	MLLW	50,000	North American Datum 1983
F00361	1991	Undetermined	20000	Undetermined
H10383	1991	Undetermined	20000	Undetermined
H10410	1992	MLLW	10000	North American Datum 1983
H10418	1992	MLLW	10000	North American Datum 1983
H10423	1992	MLLW	10000	North American Datum 1983
H10427	1992	MLLW	10000	North American Datum 1983

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H10428	1992	MLLW	10000	North American Datum 1983
H10448	1992	MLLW	10000	North American Datum 1983
H10449	1992	MLLW	10000	North American Datum 1983
H10450	1992	MLLW	10000	North American Datum 1983
H10451	1992	MLLW	10000	North American Datum 1983
F00362	1992	Undetermined	20000	Undetermined
H10452	1993	MLLW	10000	North American Datum 1983
H10453	1993	MLLW	10000	North American Datum 1983
H10454	1993	MLLW	10000	North American Datum 1983
H10455	1993	MLLW	10000	North American Datum 1983
H10457	1993	MLLW	10000	North American Datum 1983
H10460	1993	MLLW	10000	North American Datum 1983
H10485	1993	MLLW	10000	North American Datum 1983
H10492	1993	MLLW	10000	North American Datum 1983
H10497	1993	MLLW	10000	North American Datum 1983
H10521	1993	MLLW	10000	North American Datum 1983
H10522	1993	MLLW	10000	North American Datum 1983
F00356	1993	Undetermined	10000	Undetermined
F00384	1993	Undetermined	10000	Undetermined
F00390	1993	Undetermined	10000	Undetermined
F00393	1993	Undetermined	10000	Undetermined
H10523	1994	MLLW	10000	North American Datum 1983

Table A-1 – Continued

Survey ID	***Year***	***Original Vertical Datum***	***Scale/Vertical Accuracy***	***Provided Horizontal Datum***
H10525	1994	MLLW	10000	North American Datum 1983
H10526	1994	MLLW	10000	North American Datum 1983
H10527	1994	MLLW	10000	North American Datum 1983
H10528	1994	MLLW	10000	North American Datum 1983
F00397	1994	Undetermined	10000	Undetermined
F00398	1994	Undetermined	10000	Undetermined
F00401	1994	Undetermined	10000	Undetermined
F00476	2001	LWRP 1993	10,000	North American Datum 1983
H11082	2002	MLLW	10,000	North American Datum 1983
H11179	2002	MLLW	20,000	North American Datum 1983
H11228	2003	MLLW	10,000	North American Datum 1983

Appendix B. Electronic Navigational Charts

Table B-2. ENC datasets used in building the Northern Gulf Coast DEMs

Chart	*Title*	*Edition*	*Edition Date*	*Scale*
US4FL69M	Apalachee Bay	6.0	2010-09-01	1:80000
US4FL68M	Apalachicola Bay to Cape San Blas	4.1	2006-11-28	1:80000
US3GC04M	Approaches to Mississippi River	43.0	2010-11-26	1:250000
US5LA24M	Baptiste Collette Bayou to Mississippi River Gulf Outlet;Baptiste Collette Bayou Extension	34.0	2010-07-29	1:40000
US4LA32M	Barataria Bay and approaches	28.0	2010-12-02	1:80000
US3GC05M	Cape St. George to Mississippi Passes	32.2	2010-05-17	1:456394
US4LA34M	Chandeleur and Breton Sounds	22.1	2010-07-28	1:80000
US4FL74M	Choctawhatchee Bay	4.1	2010-05-26	1:80000
US5FL64M	Intracoastal Waterway Apalachicola Bay to Lake Wimico	8.1	2010-05-20	1:40000
US5FL65M	Intracoastal Waterway Carrabelle to Apalachicola Bay;Carrabelle River	15.0	2010-06-15	1:40000
US5MS11M	Intracoastal Waterway Dog Keys Pass to Waveland	39.0	2010-11-22	1:40000
US5FL63M	Intracoastal Waterway Lake Wimico to East Bay	12.0	2010-06-23	1:40000
US5LA36M	Intracoastal Waterway Waveland to Catahoula Bay	18.0	2010-11-23	1:40000
US5FL62M	Intracoastal Waterway West Bay to Santa Rosa Sound	18.0	2010-11-24	1:40000
US4LA25M	Isles Dernieres to Point au Fer	11.0	2010-06-21	1:80000
US4MS10M	Lake Borgne and approaches Cat Island to Point aux Herbes	11.1	2010-06-22	1:80000
US4LA39M	Lakes Pontchartrain and Maurepas	12.0	2010-05-06	1:80000
US5LA41M	Loop Deepwater Port Louisiana Offshore Oil Port	11.0	2010-11-04	1:50000
US4LA30M	Mississippi River Delta;Southwest Pass;South Pass;Head of Passes	19.1	2010-06-23	1:80000
US4LA33M	Mississippi River Delta;Southwest Pass;South Pass;Head of Passes	21.1	2010-09-07	1:80000
US5LA51M	Mississippi River-New Orleans to Baton Rouge	24.1	2010-07-16	1:40000
US3GC03M	Mississippi River to Galveston	37.0	2010-11-29	1:458596
US4LA35M	Mississippi River-Venice to New Orleans	33.1	2010-11-18	1:80000
US5LA37M	New Orleans Harbor Chalmette Slip to Southport	18.1	2010-09-15	1:15000
US5MS22M	Pascagoula Harbor	23.1	2010-10-05	1:20000
US5FL72M	Pensacola Bay	19.1	2010-05-10	1:30000

Table B-2 – Continued

Chart	***Title***	***Edition***	***Edition Date***	***Scale***
US4FL71M	Pensacola Bay and approaches	7.2	2010-04-05	1:80000
US5FL73M	Pensacola Bay Entrance	9.0	2010-05-14	1:10000
US5LA26M	Port Fourchon and Approaches	17.5	2010-06-22	1:20000
US5FL67M	St. Andrew Bay - Bear Point to Sulpher Point	9.0	2010-07-06	1:5000
US4FL60M	St Joseph and St Andrew Bays	8.0	2010-07-06	1:80000
US3GC06M	Tampa Bay to Cape San Blas	13.1	2010-05-25	1:456394
US4LA29M	Timbalier and Terrebonne Bays	11.1	2009-10-22	1:80000
US4LA31M	Timbalier and Terrebonne Bays	23.0	2010-11-09	1:80000

[Page left intentionally blank]